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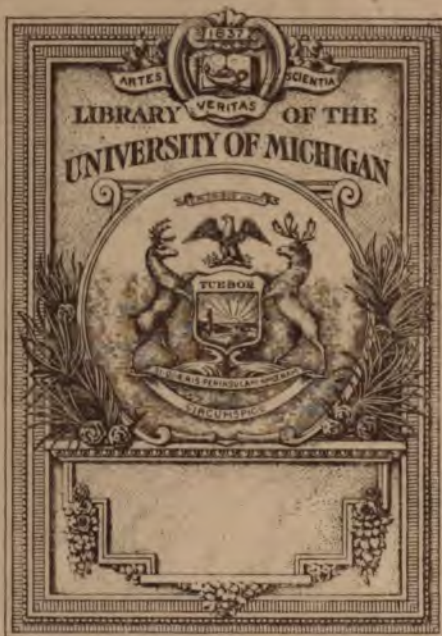
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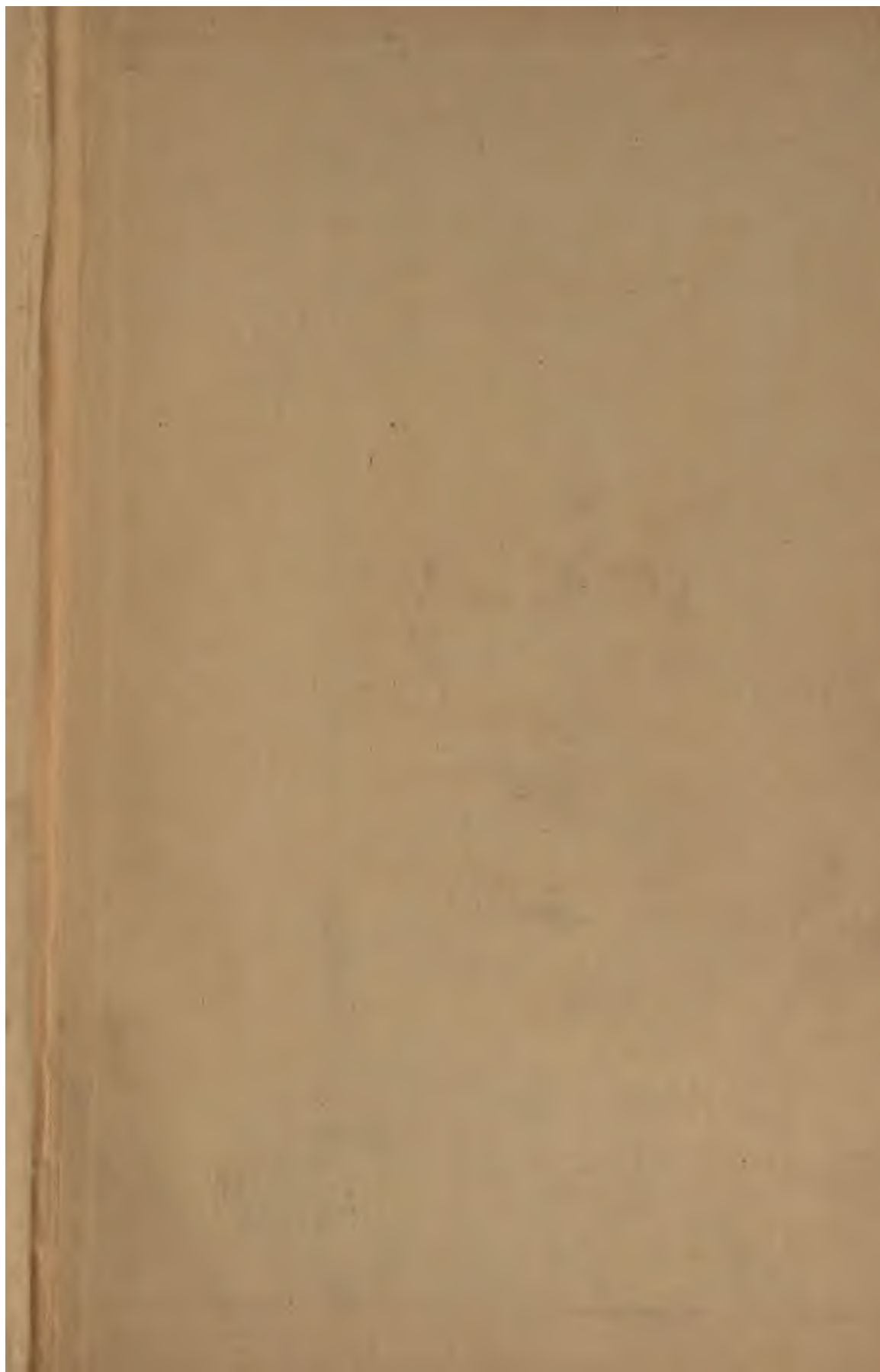
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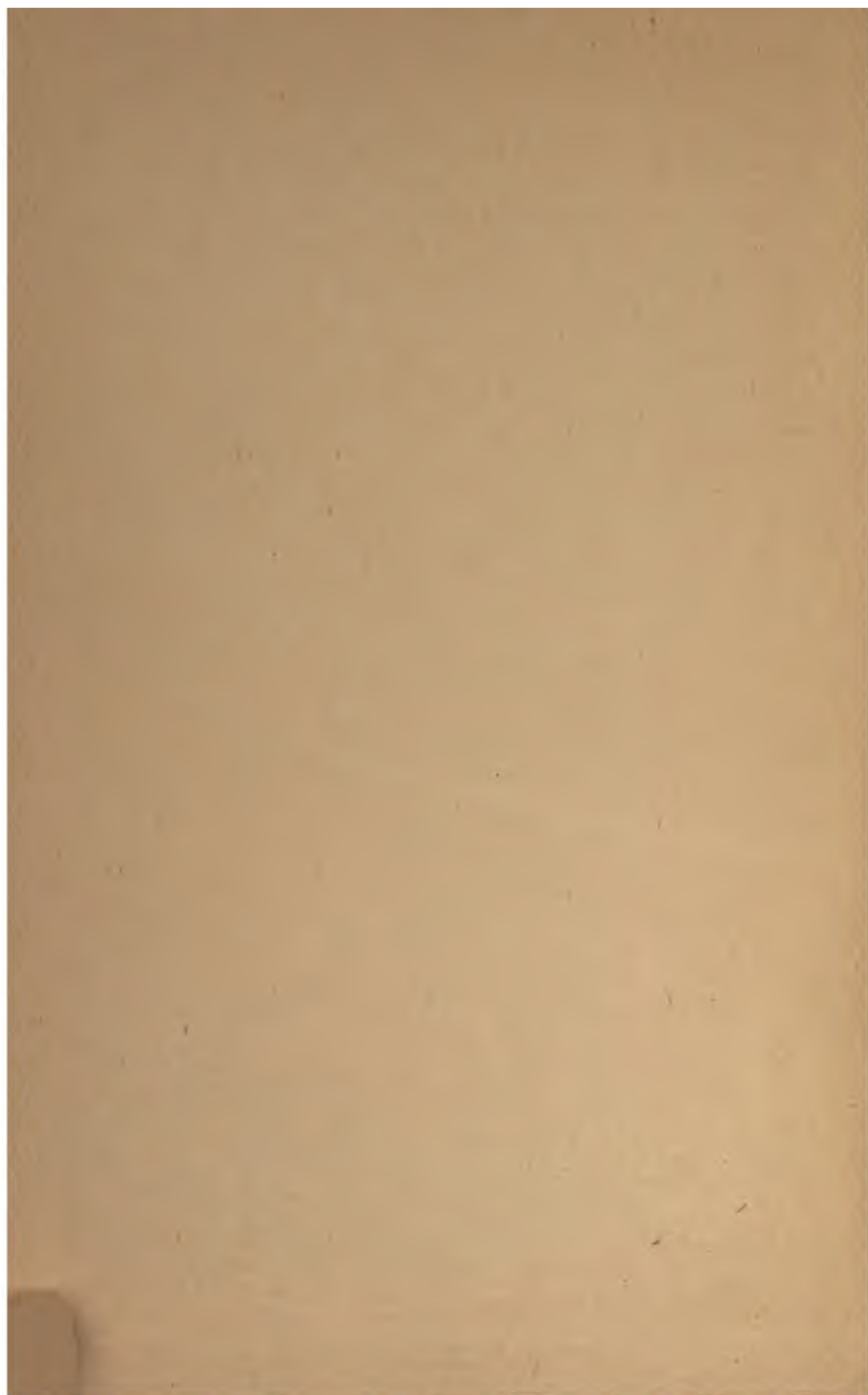
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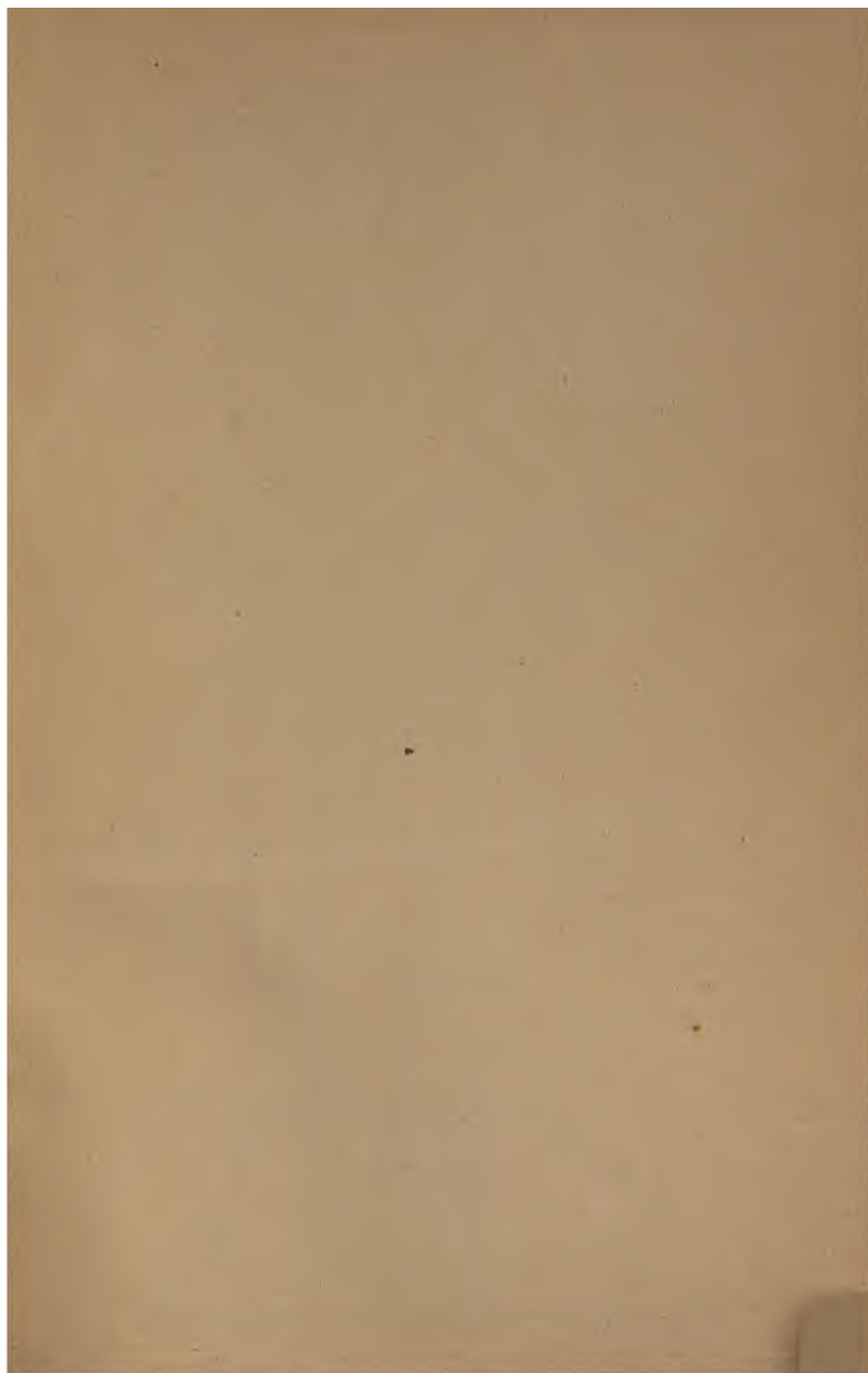
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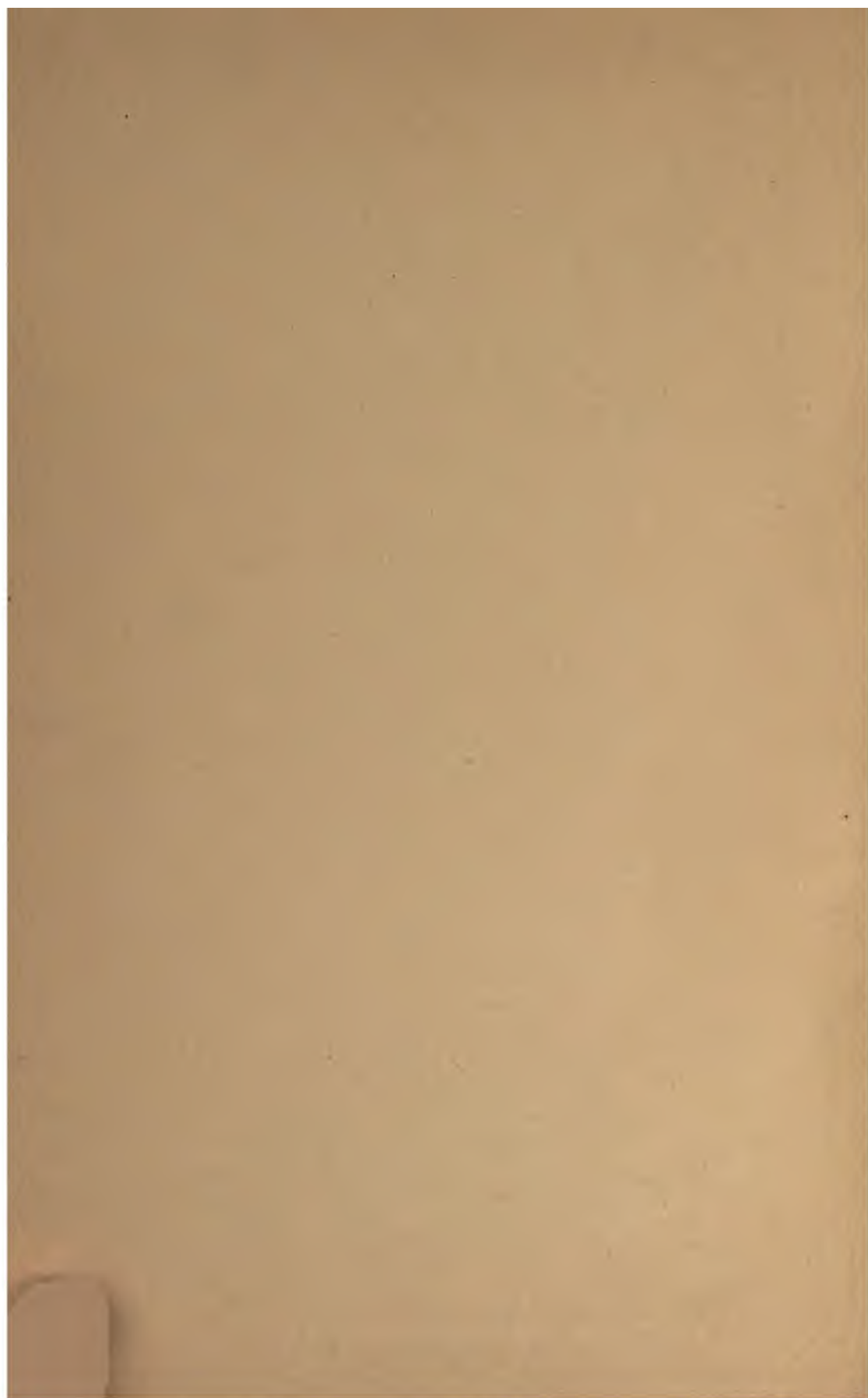


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No. 1



INHERITANCE IN SILKWORMS, I

BY

VERNON L. KELLOGG

Professor of Entomology, and Lecturer in Bionomics

with the partial collaboration of
RUBY GREEN SMITH
former Instructor in Entomology

STANFORD UNIVERSITY, CALIFORNIA
PUBLISHED BY THE UNIVERSITY
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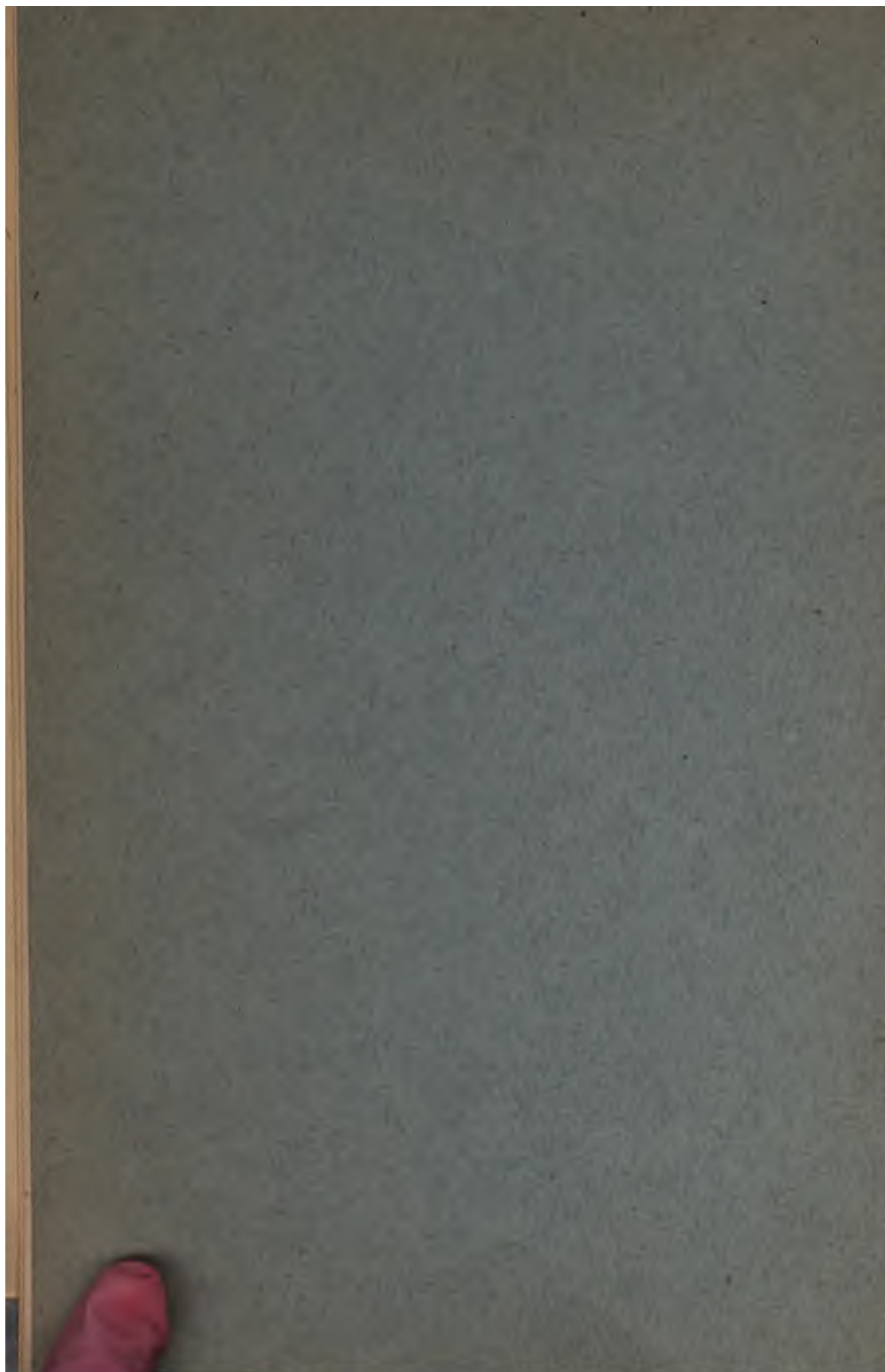
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CONTENTS.

INTRODUCTORY NOTE.	
RACES AND CHARACTERISTICS.	
DIFFERENT KINDS OF INHERITANCE BEHAVIOR.	
ALTERNATIVE INHERITANCE.	
Larval Color-pattern.	
Cocoon Colors.	
Larval and Cocoon Characters in Same Matings.	
Prepotency of Sex and Vigor.	
STRAIN AND INDIVIDUAL IDIOSYNCRASIES.	
DOUBLE MATING.	
FLUCTUATING VARIATIONS AND NON-ALTERNATIVE INHERITANCE.	
Egg Character.	
Subsidiary Larval Markings.	
Wing-pattern.	
Wing-venation.	
MISCELLANEOUS.	
Double Cocooning.	
Appearance and Behavior of Sports.	
Fertility as Affected by Age of the Germ Cells.	
ECONOMIC ASPECTS OF SILKWORM INHERITANCE.	
SUMMARY OF RESULTS AND CONCLUSIONS.	
APPENDIX: Abstracts and Summaries of Papers on Silkworm Biology,	
Previously Published by the Author.	
Food Conditions in Relation to Sex Differentiation.	
Forced Pupation.	
Loss of Weight During Pupal Life.	
Variations Induced in Larval, Pupal and Adult Stages by Controlled	
Varying Food Supply.	
Regeneration in Larval Legs and Caudal Horn.	
Influence of the Primary Reproductive Organs on the Secondary Sexual	
Characters.	
Sex Differentiation in Larvæ.	
Moth Reflexes.	
Artificial Parthenogenesis.	

Since 1900 the writer has given attention to the general biology of the familiar mulberry silkworm. This attention has taken the form of considerable experimental work on such problems as the causes and time of sex differentiation, regeneration of larval parts, influence of the

primary reproductive organs on the secondary sexual characters, reflexes of the moths, artificial parthenogenesis, etc. The results of much of this work have already been published as papers in various scientific journals. A list of these papers follows and an abstract of each one of them may be found in the Appendix to the present paper.

(with R. G. Bell) Notes on Insect Bionomics, in *Jour. Exper. Zool.*, v. 1, pp. 357-367, August, 1904.

(with R. G. Bell) Variations Induced in Larval, Pupal and Imaginal Stages of *Bombyx mori* by Controlled Varying Food Supply, in *Science*, N. S. v. 18, pp. 741-748, Dec., 1904.

Regeneration in Larval Legs of Silkworms, in *Jour. Exper. Zool.*, v. 1, pp. 593-599, 10 figs., Dec., 1904.

Influence of Primary Reproductive Organs on Secondary Sexual Characters, in *Jour. Exper. Zool.*, v. 1, pp. 601-605, Dec., 1904.

Some Silkworm Moth Reflexes, in *Biol. Bull.*, v. 12, pp. 152-154, Feb., 1907.

Sex Differentiation in Larval Insects, in *Biol. Bull.*, v. 12, pp. 380-384, 8 figs., May, 1907.

Artificial Parthenogenesis in Silkworms, in *Biol. Bull.*, v. 14, pp. 15-22, Dec., 1907.

At the same time that these miscellaneous studies in silkworm biology were begun, a series of planned and controlled rearings was started (one generation a year) to test the behavior in heredity of fluctuating and sport variations of larvæ, cocoons and adults. Also experiments and rearings were carried on to test structural and physiological modifications which might be induced by varying food supply (both as to character and quantity) and the possible inheritance of these modifications. From 1904 on the work has been turned chiefly to a study of the modes of inheritance of various racial characters of eggs, larvæ and cocoons, involving controlled pure and hybrid matings of individuals of some fifteen races. This study of heredity has served to test, for the silkworm, the Mendelian principles of inheritance, as well as the actuality of the potency in heredity of vigor, of sex, and of special characters. Finally the hypothesis of individual and race idiosyncrasies in matters of inheritance has been tested. The present paper is a first contribution of data and results derived from this general study of silkworm inheritance. Any discussion of a possible practical application of these results in connection with commercial silk culture is reserved for a future paper.

From 1900 to June, 1905, Mrs. R. G. Bell (now Mrs. R. G. Smith),

at that time Instructor in Entomology, was associated with the present writer in all of the silkworm work, and fully deserves therefore the title of collaborator. Certain data also have been obtained from the careful and extensive studies of Instructor McCracken, who has given special attention during the last three years to the inheritance of the *moricaud* larval sport and to the behavior of bivoltinism as a heritable character.

I am indebted to Professor E. Verson, director of the royal silk culture station at Padua, Italy, to Mr. S. I. Kuwana, entomologist of the imperial agricultural station at Nishigahara, Tokyo, Japan, and to others, for eggs of various races. Dr. L. O. Howard, Chief of the Bureau of Entomology of the U. S. Dept. of Agriculture, helped out the work in one of the years by an appropriation for assistance. Mrs. Carrie Williams and Miss E. L. Story of San Diego, California, rendered very efficient and faithful help in the 1907 rearings. Drawings for the present paper were made by Mary Wellman and Maud Lanktree as indicated on the respective plates. To all of these, and to numerous helpers, especially Isabel McCracken and R. W. Doane, in the arduous and exacting labor of rearing, observing, and tabulating through the past six years, the writer expresses his obligation and gives his sincere thanks.

RACES AND CHARACTERISTICS.

During the course of the work fifteen different silkworm races have been bred pure and used in hybridization, but a few of these have been used much more than the others. These various races (Bagdad, Istrian, Japanese White, Japanese Green, Chinese White, Italian Yellow, French Yellow, Persian Yellow, Turkish and French Yellow, etc.) are distinguished from each other by characteristics of the egg, the larva, the cocoon and, to some degree, of the adult. The varying egg characters are size, shape, color and degree of adhesiveness. The larval characters are size, external appearance and, chiefly, color and pattern. The cocoon characters are size, shape, character of silk as to tenacity, diameter, length, etc., of the thread, and, most conspicuously, color. The adult characters are size, and degree and character of patterning of wings.

These characteristics are all of course affected by fluctuating variation and by occasional sport (reversional or mutational) variation, but for cocoon colors, larval colors and patterns, adhesiveness of egg and size of egg, and certain "commercial" characters of the silk, as tenacity, diameter and length of the thread, the races are well separated and have long been bred pure.

The mulberry silkworm has been domesticated and ameliorated by man for about five centuries. The exact feral species from which it is derived is not certainly known. It seems most probable that the home of the wild progenitor was (perhaps still is) in the mountains of northern India.

As with poultry, cattle, horses, dogs, sheep, swine, pigeons, many races have been established in many lands, and much careless and useless hybridization and selection has been indulged in. Out of it all there has been of course, unconsciously and consciously, a steady increase in the output and in the betterment in quality of the silk produced by the silkworm individual. Commercially valuable characteristics of the silk, and behavior, resistance to disease, and "tame-ness" of the larva have been the points striven for by breeders. But along with these, other characteristics, correlated or independent, have become fixed in various races and are useful to the experimental student of inheritance.

For the purposes of our studies the nature and distinctness of the varying distinguishing characteristics of the races and their steadfast-

ness in transmission (in pure matings) were the important matters of silkworm differentiation rather than the geographical or historical or commercial relations of the various races. Therefore no list of the races with their particular characters will be given, but instead will be given a catalogue and description of the various characteristics of eggs, larvæ, cocoons and adults. These descriptions can be made brief because of the careful illustrations (see Plates I and II) which will readily give a clear understanding of the character conditions.

Egg characters.

Adhesive (i. e., sticking, when oviposited, tightly to the object on which they are deposited). Characteristic of all races used except the Bagdad race.

Non-adhesive (i. e., eggs loose, unattached to the paper of the mating box). Characteristic of the Bagdad race.

No other egg characters have so far been made use of in my studies.

Larval characters (last larval instar).

White without darker pattern. Characteristic of several races, as Chinese White, and others. (Pl. I, figs. 1, 7; Pl. III, figs. 1, 5.)

White with certain regular but few markings, as Bagdad, etc. (Pl. I, fig. 3.)

White with well marked darker pattern. Characteristic of Japanese White and others. (Pl. I, fig. 4; Pl. III, figs. 3, 7.)

Tiger-banded (i. e., black or black-brown transverse segmental bands). Characteristic of a sub-race of Italian Salmon race. (Pl. I, fig. 2; Pl. III, fig. 2.)

Moricaud (i. e., a close pattern of black-brown lines all over the body so as to make the whole larva a "darky"). A sport which has appeared in several races in our laboratory, as Italian Yellow, Bagdad, etc., and which has been established in our laboratory as a nearly pure sub-race of Bagdad. (Pl. III, figs. 4, 8.)

Cocoon characters.

White; characteristic of Bagdad, Japanese White, Chinese White and other races. (Pl. IV, figs. 1, 2, 3, 4.)

Yellow, of various shades from lemon to golden; characteristic of Istrian, Italian Yellow, and other races. (Pl. IV, figs. 8, 9.)

Salmon, or pale yellowish pink; characteristic of Italian Salmon race. (Pl. IV, figs. 13, 14, 15.)

Green; characteristic of Japanese Green race. (Pl. IV, fig. 7.)

Characteristics of shape.

Several, as constricted, broad-ended, tapering, etc. (see Pl. IV), but not used in the present studies.

Adult characters.

Patterning of the wings (see Pl. II), venation of the wings, darkness of wings and body, etc., but no character found to be distinctive of a race.

In addition to these differences still other racial ones occur in connection with properties of the silk, but with these I have nothing to do in this paper, as they have not been used by us in the inheritance studies.

Other characters not racial but occurring as individual variations have been noted and some have been made use of to some extent in the studies. For example, melanism of the moths (darky moths) and the degree of patterning of the wings, variations in the wing-venation of the moths, various teratologic sports, the phenomenon of double and triple cocooning, the flight capacity of the moths, etc., have all been subjects of more or less observation and experiment.

As the characteristics used will be described in more detail in connection with the particular accounts of studies in which they are used, this general statement of the variety of characters available to the student of silkworm variation and heredity may suffice. It should be stated at once, however, that among these various silkworm characteristics or variations some are distinctly alternative or discontinuous in character while others are continuous or fluctuating in variational character. Thus in this one species of animal, opportunity is well afforded for studies of the behavior in inheritance of both types of variations.

DIFFERENT KINDS OF INHERITANCE BEHAVIOR.

The silkworm is a very convenient animal with which to experiment in matters of inheritance. The matings can be made with ease and certainty. Many of the races have been bred pure for hundreds of generations and are very stable and reliable. The characters available for observation are well-marked and easy to describe and illustrate, and represent inheritance in different well-marked life-periods of the animal so that the inheritance of characters peculiar to one life-period can be compared with that of characters of another life-stage. Finally the animals can be reared in large numbers in comparatively limited space, and thus extensive series and many repetition lots be obtained for a basis for generalizations.

This last point is one on which I wish to lay stress. *My conclusions as to the behavior in inheritance, especially as regards its uniformity or non-uniformity, of various silkworm characteristics would have been quite different from what they are at present if I had not made use of numerous repetition lots. It is on the basis of these repetition lots that my conclusions as to strain and individual idiosyncrasies in silkworm heredity are based.*

It is perfectly plain from the results of my experiments (as well as from those of Coutagne and Toyama, to be referred to in a moment) that different silkworm characters behave differently in inheritance. (At least this is perfectly plain unless some ingenious analyst like Bateson by a combination of real analysis with added hypotheses of "determiners," or what not, undertakes to make it not perfectly plain.)

These different characters are those of various life-stages, as larval, pupal, or adult, but they are not necessarily like or unlike each other in their inheritance behavior on the basis of any distinction of life-stage. They differ in inheritance behavior simply on the basis of difference in characteristic. These inheritance behavior differences consist in some characteristics being alternative (and usually essentially Mendelian) in inheritance, as larval pattern (white, patterned, tiger-striped and moricaud), cocoon color, etc., while others are particulate or blend in inheritance. The former are discontinuous or non-intergrading variations or differences, the latter are fluctuating or continuous, as wing pattern of adults, richness of silk in cocoon, adhesiveness of egg, etc.

Some of these latter characters cannot be controlled even by most careful and persistent selection, and in this give a strong negative (as do some of the characters of *Leptinotarsa* experimented with by Tower) to the familiar declaration of the selectionist that there is no limit to the quantitative modification of characteristics by means of selection. "Tell me what you want made out of this plant or animal and I'll make it," exclaims the selectionist breeder. But most times he can't, and in those times that he can he will most often do it by hybridization, not pure selection. And this hybridization he will find necessary despite the start in any direction he ought to get from "infinite fortuitous variation."

Coutagne and Toyama.—Before setting out any of the data and conclusions derived from my own work with silkworms I must call attention to two previous studies, those respectively of Coutagne (*Recherches Experimentales sur l'Hérédité chez les Vers a Soie*, published as No. 422, Serie A, Thésés présentées a la Faculté des Sciences de Paris, pp. 1-194, plates I-XI, 1902), and Toyama (*Studies on the Hybridology of Insects: I, On some silkworm crosses, with special reference to Mendel's law of heredity*, published in *Bulletin of the College of Agriculture, Tokyo Imperial University*, vol. VII, pp. 259-393, plates VI-XI, 1906). The work of Coutagne was done and his thesis written without knowledge on his part of the experiments and conclusions of Mendel and of Mendel's discoverers, De Vries, Correns and Tschermak, but a part of the work done by the French student and some of his results are distinctly in line with the Mendelian or alternative inheritance principles of heredity. Coutagne, however, gave his principal attention and effort to the modification of fluctuating characters, especially those of quantity and quality of silk, by persistent selection. His work has been recognized and estimated pretty fairly by such thorough-going Mendelian students as Bateson, and needs no particular exploitation or summing up by me.

Toyama's work, in contrast with Coutagne's, has been conducted in the light of a full knowledge of Mendel's work and of that of his successors, and has indeed been directly carried on to test the application of Mendelian principles to silkworm inheritance. It is of interest—of very lively interest, indeed, to me—to note how closely parallel Toyama's work and that part of mine devoted to the same end have been going on, each of us presumably without knowledge of the other's work. We began at practically the same time—Toyama in 1900, I in 1901—and have used the same characteristics in the same way with

readily comparable although (as will be pointed out) not wholly identical results. The differences in the actual work of crossing and rearing seem chiefly to be that Toyama has brought larger proportions of the individuals in each of his experimental lots safely through to maturity (or cocooning time), while I have used a larger number of what may be called repetition lots; that is, lots of exactly similar parentage to serve as checks on each other. The differences in results and conclusions reached by Toyama and myself will be found, I believe, to rest largely on these differences in actual rearing methods.

Toyama has published his results first, and has put into admirably well organized and lucid arrangement his statements of data, results and generalizations. He finds and brings out clearly the indisputable alternative (or Mendelian) character of the inheritance behavior of certain characteristics. He finds a few exceptions to this kind of inheritance, both as to characteristics and as to individual cases of the usually Mendelian characteristics. On the whole he stands as a strong exponent of the generally Mendelian character of inheritance in the silkworms.

In those respects, which are many, in which my own experiments, carried on simultaneously with Toyama's, confirm his published conclusions it will be sufficient for me to do away almost entirely with any exposition of data and details of rearing, and to give simply summary statements of the results of a great deal of work. It is unnecessary to remind any experimental student of heredity of the laborious, exacting and anxiety-breeding character of this kind of work. The results of the expenditure of much energy, time and money can be stated in a few sentences. And especially where these sentences take on the character of simple confirmation of another man's already stated results and conclusions they may be fewer still. Such is my position in the present writing concerning that part of my seven years' work which has absorbed most time and attention. But this confirmation is of course worth while. Our science of heredity, based on experimental study, is too new not to welcome gladly independent confirmation of results already once attained. Such confirmation shows us that we are working on sure ground.

It is where my results disagree with Toyama's, or, perhaps, better expressed, where by circumstance of a considerable recourse to repetition some conspicuous exceptions have been noted, indicating a less rigorously controlled or rigidly regular behavior of inheritance, that I shall use more words than are used in discussing the cases of clear

confirmation. These cases of disagreement or of modification are mostly to be found referred to in the section entitled "Strain and Individual Idiosyncrasies."

ALTERNATIVE INHERITANCE.

LARVAL COLOR—PATTERN.

The larval color pattern types that show alternative inheritance are four: (1) moricaud or "darky" (Pl. III, figs. 4, 8); (2) tiger-band or zebra (Pl. I, fig. 2, Pl. III, fig. 2); (3) patterned (Pl. I, fig. 4, Pl. III, figs. 3, 7), and (4) white (Pl. I, figs. 1, 7; Pl. III, figs. 1, 5). The white type shows several sub-types which are, however, of the nature of fluctuating variations (see p. 40). Of these types the moricaud is a melanic sport which has appeared in three different races in our laboratory; the tiger-banded is a dimorphic (or better, dichromatic) form of the Italian Salmon race; the patterned is characteristic of the Japanese White and other races, and the white is characteristic of the Bagdad, the Chinese White, the Istrian and other races.

Moricaud type.—In 1904 the first examples of moricaud larvæ appeared in the laboratory. Two moricaud individuals appeared in a lot of Italian Salmon race (eggs received from Sondrio, Italy). One of these died as larva; from the other a male moth was obtained. This was mated with a female of Chinese Cross race (white larval type). The offspring were, as to larval character, equally divided between the paternal (moricaud) type and the maternal (white) type. There were no intergrades. In the second generation rearings all the larvæ derived from mating moths of white larval type together were white, while in cross matings, i. e., moricaud larvæ with white larvæ, lots were obtained composed of moricaud larvæ and white larvæ without intergrades. On account of disease the lots were too small to give the numbers of each kind of larva any value as revealing the true numerical relation of the two types.

In 1905 a single moricaud larva appeared in a Bagdad (white larva) lot. This larva produced a female moth, which was mated with a male Bagdad (from white larva). The young (1906) of this mating were 154 white larvæ and 153 moricaud larvæ with no intergrades. Ten second generation lots were reared (in 1907) by making the following inbred pure and cross matings:

(536) moricaud X moricaud, producing all moricaud larvæ.

(444) white X white, producing all white larvæ.

(470) white X moricaud, producing 11 white larvæ and 5 moricaud. (Lot so reduced by disease as to make the numerical proportions of no significance.)

(564) white X Galbin Italiano race, white larva, producing all white.

(440) moricaud X Japanese Green race, white larva, producing 5 moricaud and 3 white. (Lot so reduced by disease as to make numbers of no significance.)

(563) white X Italian Salmon race, tiger-banded larva, producing 135 tiger-banded, 62 white and 2 moricaud.

(343) white X Italian Yellow race, white larva, producing all white.

(441) moricaud X Japanese White race, patterned larva, producing 45 moricaud and 46 patterned.

(468) moricaud X Istrian race, white larva, producing 120 moricaud and 154 white.

(475) moricaud X Persian Yellow race, white larva, producing 17 moricaud and 19 white.

These few rearings show that moricaudness in larvæ is a dominant Mendelian character, and whiteness a recessive. In all the outmatings with other races than the Bagdad (Nos. 564, 440, 563, 343, 441, 468 and 475) the Bagdad moricaud must have been a cross-bred (heterozygote) individual.

I have had a single moricaud larva appear in a lot of white Chinese Cross race, and a single one in a white Galbin Italiano race.

In 1904 a single larva in a lot of 100 (race unknown) appeared of a "remarkable warm tawny brown clouding over the whole body, the skin being everywhere strongly dotted and finely lined, the spots and lines being a warm brown instead of a blackish brown or blackish lead color characteristic of other moricaud sports."

In some lots of larvæ reared (experimentally) under conditions of extreme humidity from time of hatching to pupation, a marked tendency toward an abundant fine dotting, aggregating into short curved lines was shown, so that the bodies of the worms had a very noticeable blackish or moricaud appearance.

A detailed study on extensive scale of the inheritance behavior of moricaudness is being made in our laboratories by Miss McCracken.

Tiger-banded or Zebra type.—The tiger-banded or zebra larval type (Pl. I, fig. 2, Pl. III, fig. 2) is a perfectly distinct and strongly marked type and appears as a regular dimorphic, or better, dichromatic, larval variant in the Italian Salmon race. In relation to the unstriped or white type it is dominant in the Mendelian sense and usually behaves with almost perfect regularity in conformity with Mendelian

principles. Hundreds of examples of this could be adduced from my rearings, both from pure and crossed matings (with reference to larval pattern) within the Italian Salmon race and to outbred matings with various other races, as Bagdad, Istrian, Chinese White, etc., etc., having larvæ of white type. A few cases out of these hundreds will suffice. In all of the scores of matings in the past five years within the Italian Salmon race, testing the Mendelian behavior or relation in inheritance of the two larval types, tiger-banded and white, the two characters behaved in rigorous Mendelian manner, tiger-banded being dominant, white recessive. Never did intergrades appear, never did a tiger-band larva appear in a white X white mating, and wherever the reared cross-bred lots were carried through in something like their full strength the proportions of the two types called for by Mendelian inheritance were closely approximated.

In outbred matings, with races of white larval types, the results may be summed as follows:

Italian Salmon crossed with Bagdad. Tiger-band characteristic is dominant in matings of tiger-band Italian Salmon larvæ with Bagdad larvæ (always white). In second generation rearings from hybrid matings the parental characters segregate according to Mendelian proportions, in many cases the 3 to 1 proportions being almost exactly followed. White larvæ mated together either in F_1 race crosses or in F_2 and succeeding hybrid generation crosses never produce a tiger-band larva. Reciprocal crosses (as to sex) in both F_1 and succeeding generations behave similarly; i. e., show no dominancy of sex.

Italian Salmon crossed with Istrian; Italian Salmon crossed with Galbin Italiano; Italian Salmon crossed with Chinese White, and other crosses of Italian Salmon with white larva races. In these race crosses tiger-bandedness of the larvæ behaved regularly as a Mendelian dominant and whiteness as a recessive, and the various familiar 3 to 1, 2 to 1 and 1 to 1 proportions dependent upon the assumed germ cell character of the dominant-carrying member of the pair were all closely approximated in the many lots bred.

Patterned type.—The "patterned" type of larva (Pl. I, fig. 4; Pl. III, figs. 3, 7) is shown characteristically by the Japanese White, Italian White and certain other races. Although subject to considerable fluctuating variation (see p. 43) it behaves in inheritance usually as a unit characteristic and is alternative in transmission. It is recessive to tiger-bandedness but dominant to whiteness. But it seems not to be really a unit character in that in cross matings with tiger-bandedness

(as in Japanese White X Italian Salmon, and Italian White X Italian Salmon) not only tiger-banded larvæ and patterned larvæ appear but also tiger-banded-patterned larvæ (Pl. I, fig. 5) and pure white larvæ. And this in the first generation as well as in later ones. In matings of patterned larvæ with white ones (race crosses) pattern is regularly dominant, and follows Mendelian proportions. Occasionally a pure white larvæ or two appear in a pure Japanese White race lot (patterned larvæ). For example, in a 1905 pure race crossing of Japanese White, two white (unpatterned larvæ) appeared, and these mated together (they were fortunately male and female) produced a lot of uniformly white larvæ.

White type.—White is regularly recessive to all of the other larval color-pattern types. And white larvæ mated with white never produce any but white larvæ.

COCOON COLORS.

The various cocoon colors represented by the races being reared in my laboratory are white, green, pale pinkish yellow (or salmon), lemon yellow, and golden yellow (see Plate IV). To these colors, which are race characteristics, I have added as the result of "break-downs" after hybridizations a long series of mid-shades connecting any pair of members of the racial series. The facts and results of these "break-downs" are to me the most interesting data, perhaps, that the silkworm work has revealed, for I seem to see in them a significance of prime importance. The pointing out of this significance and the facts of the breaking down of the racial color types may be passed for the moment, however, to attend to what phenomena of alternative and Mendelian inheritance may be discovered in these cocoon types.

Mating gold yellow (Istrian race) with pure white to faintly greenish white (Bagdad race) produces sometimes an all gold-yellow first generation with splitting in Mendelian proportions in the second generation lots as in the following example:

F₁ ♂ Istrian (gold-yellow) X ♀ Bagdad (white); produced all gold-yellow cocoons.

F₂ Hyb. yellow X hyb. yellow; produced 64 yellow, 24 white cocoons.

F₂ Hyb. yellow X hyb. yellow; produced 61 yellow, 28 white cocoons.

But this is not always the result of a gold-yellow X white mating, even using the same races. As an example:

F₁ ♂ Bagdad (white) X ♀ Istrian (gold-yellow); produced all white cocoons.

F₂ Hyb. white X hyb. white; produced 77 white, 17 yellow cocoons.

F₂ Hyb. white X hyb. white; produced 62 white, 15 yellow.

This latter example is also a Mendelian type of inheritance, but the difficulty comes when it is compared with the former example. The dominance in one is with yellow; in the other with white. Note that the two are reciprocal crosses. The dominance has followed the male. But necessarily so? For answer take another example from this same Bagdad-Istrian series of crossings:

F₁ ♂ Bagdad (white) X ♀ Istrian; produced 31 white cocoons, 21 gold-yellow cocoons.

F₂ Hyb. white X hyb. white; produced 57 white, 31 gold-yellow cocoons.

F₂ Hyb. white X hyb. white; produced 51 white, 18 gold-yellow cocoons.

F₂ Hyb. yellow X hyb. yellow; produced 86 yellow, 34 white cocoons.

F₂ Hyb. yellow X hyb. yellow; produced 42 yellow, 7 white cocoons.

F₂ ♂ Hyb. white X ♀ hyb. yellow; produced 40 gold-yellow, 26 white cocoons.

F₂ ♂ Hyb. yellow X ♀ hyb. white; produced 36 white, 29 gold-yellow cocoons.

Thus within a group of the same race crosses first one color and then the other proved dominant or neither was dominant. But in all cases the inheritance was strictly alternative, never particulate or blended.

Using other races of yellow cocooners and other races of white cocooners various similarly conflicting results were obtained. For example, in Italian Yellow X Chinese White, yellow was dominant; in Italian Yellow X Japanese White, yellow was dominant; in Turkish and French Yellow X Bagdad White, white was dominant; in Istrian Yellow X Chinese White, yellow was dominant; in Istrian Yellow X Japanese White, yellow was dominant; in Persian Yellow X Chinese White, yellow was dominant; in Persian Yellow X Bagdad White, white was dominant; in Italian Yellow X Italian White, approximately half of the offspring of generation F₁ were white and half of them yellow.

In crossing yellow with green, first generation results were: in Istrian Yellow X Japanese Green, offspring were all yellow; in Persian Yellow X Japanese Green, a majority of the young were yellow, a minority green (numbers too small to be of significance as to proportions); in Italian Yellow X Japanese Green, majority of the offspring were yellow, minority green (numbers were too small to be of significance as to proportions).

In crossing white and green, first generation results are: in Bagdad White X Japanese Green, all offspring are *yellow*.

In crossing yellow and salmon, as in Persian lemon Yellow X Italian Salmon, the offspring represented all shades from pale salmon to golden yellow; in Istrian golden Yellow X Italian Salmon, the offspring were salmon.

In crossing white and salmon as in Bagdad White X Italian Salmon, salmon is usually dominant (numerous cases of the dominance of white, however, see Strain and Individual Idiosyncrasies) but the cocoons are not of single salmon tint characteristic of the Italian Salmon race but are of all shades from very pale or whitish salmon to very yellowish salmon or indeed definitely yellow even golden. But in second generation lots produced by intermating hybrids the white color usually appears again as a Mendelian recessive distinct from the pale to yellow salmon shades constituting a Mendelian dominant. In some white and salmon crosses as Italian White X Italian Salmon, white was dominant. For example of the breaking of salmon into all shades of pale salmon to golden-yellow:

F₁ ♂ Bagdad White X ♀ Italian Salmon; produced all salmon cocoons.

F₂ Hyb. salmon X hyb. salmon; produced 28 pale to yellow salmon and 7 white cocoons.

F₂ Hyb. salmon X hyb. salmon; produced 30 pale to yellow salmon and 15 white cocoons.

F₁ ♂ Italian Salmon X Bagdad White; produced all yellowish salmon to strong yellow cocoons.

F₂ Hyb. yellow salmon X hyb. yellow salmon; produced 23 pale to yellow salmon and 19 white cocoons.

F₂ Hyb. yellow salmon X hyb. yellow salmon; produced 50 salmon to yellow and 16 white cocoons.

The behavior of cocoon color crosses is evidently so erratic (at least is *apparently* so erratic) that it may more appropriately be discussed in the section on "Strain and Individual Idiosyncrasies" rather

than in this section which is concerned primarily with recording Mendelian behavior. Cocoon colors often follow Mendelian proportions but are not rigorously related as dominant and recessive to each other; and are not even rigorously alternative.

It should be noted in this connection that whereas I have found the larval color pattern characteristics to behave for the most part in very satisfying Mendelian manner, being rigidly alternative in inheritance and following in their transmission with close approximation the Mendelian proportions, I have found the cocoon colors to be much less consistent in behavior.

Toyama on the other hand found both larval and cocoon characters to be equally consistent and Mendelian in behavior.

LARVAL PATTERN AND COCOON COLORS IN THE SAME MATINGS.

It is of interest to note the results in matings combining crosses of opposed larval patterns and opposed cocoon colors at the same time.

In the first place the occurrence of typical Mendelian two-pair combinations may be noted; as in crossings of Bagdad white larva, white cocoon, with Italian Salmon, tiger-banded larva, salmon yellow cocoon, where in first generation all the larvæ are tiger-banded and all the cocoons salmon, *or white* (see reference to this in section on Strain and Individual Idiosyncrasies), with the second generation lots from intermated hybrids breaking into 3 to 1 of tiger-banded to white larvæ and inside of each of these into 3 to 1 salmon to white (*or white to salmon*) cocoon lots.

But I want particularly to call attention to the fact that in these crossings of combined opposed larval and cocoon characteristics we are dealing with characters of different life stages of the animals and that we can often note the interesting fact of the offspring following the paternal parent in a characteristic of one life-stage and the maternal parent in a characteristic of another life-stage. For example the following is a type of the inheritance behavior of the larval and cocoon characteristics in scores (hundreds indeed) of lots: ♂ Italian Salmon, tiger-banded larva, salmon yellow cocoon, X ♀ Bagdad, white larva, white cocoon; produced all tiger-banded larvæ and all white cocoons.

Such examples only serve to bring out in still stronger relief the fact that the inheritance behavior is a function of the character not of the influence of the parent.

In numerous other cases we find the inheritance in both larval and cocoon characteristics agreeing in following a single one of the

parents, as where all the young of a cross-mating between a tiger-banded larva, salmon cocoon race, as Italian Salmon, and a white larva white cocoon race as Chinese White, being tiger-banded larvæ spinning salmon-colored cocoons. But these cases of coincidence in both larval and cocoon characters being those of either the father or the mother are really only coincidences in the possession by the one parent of the two dominant members of a double pair of allelomorphs. It is still the dominance of the character and not of the parent that determines the condition of the offspring as concerns the appearance or lying latent of the character in question.

It is unfortunate that none of the adult characters has yet been found to be of the alternative Mendelian inheritance type, so that a comparison of the transmission of characters in all three stages, larval, pupal and imaginal, might be made. The adult variations in wing-pattern and in the color and adhesiveness of the eggs are fluctuating and not alternative in character.

PREPOTENCY OF SEX AND VIGOR.

It was desired to determine whether the dominance of a character in heredity could be weakened or destroyed by weakening or lessening the vigor of the parent representing the character, or whether in general any prepotency in heredity was due to vigor or sex.

Experiments were begun, therefore, in 1904 by rearing certain individuals under conditions of short food and others of full food and making matings between these starvelings and full-fed vigorous individuals. The individuals used for experiment were selected so as to represent two races offering a Mendelian pair of allelomorphs both as to larval and cocoon characteristics. Examples of these 1904 matings and their results are as follows:

A male starveling of race Italian Salmon, zebra larva, salmon cocoon, was mated with a full-fed, vigorous female of race Chinese White, unpatterned white larva, white cocoon. The young were all zebra larvæ.

A male starveling of Italian Salmon race, zebra larva, salmon cocoon, was mated with a full-fed, vigorous female of race Chinese White, unpatterned white larva, white cocoon. The young were 70 zebra larvæ and 75 unpatterned white larvæ; all the cocoons were salmon.

A full-fed, vigorous male of Italian Salmon race, zebra larva, salmon cocoon, was mated with a starveling female of Japanese White

race, patterned white larva, white cocoon. Two-thirds of the young were blended zebra and patterned larvæ, and one-third were patterned white larvæ.

In the first case the starveling male was undoubtedly a homozygote; in the second case a heterozygote. In the first case the weak condition of the starveling male did not affect or modify in any degree the characteristic dominance of the zebra over the white larval type. In the third case there seems to be an interesting varying from the Mendelian or alternative type of inheritance to an unmistakable and perfect blending in the eggs of two-thirds of the progeny.

In 1905 another set of experiments along this line of testing the prepotency of vigor and sex was made. The following examples of these matings and their results may be referred to:

A male starveling, Italian Salmon, zebra larva, salmon cocoon, mated with a vigorous female, Bagdad race, white larva, white cocoon. Offspring all zebra larvæ; cocoons showing many shades of color from greenish white through salmon and dull yellow to golden yellow.

A male starveling, Italian Salmon, zebra larva, salmon cocoon, mated with vigorous female, Bagdad, white larva, white cocoon. Offspring were all zebra larvæ.

A male starveling, Italian Salmon, zebra larva, salmon cocoon, mated with vigorous female, Bagdad, white larva, white cocoon. Offspring were 133 zebra larvæ and 129 white larvæ. Cocoons all salmon.

A vigorous male, Italian Salmon, zebra larva, salmon cocoon, mated with female starveling, Bagdad, white larva, white cocoon. Offspring all zebra larvæ; cocoons all white.

A male, vigorous, Italian Salmon, zebra larva, salmon cocoon, mated with female starveling, Bagdad, white larva, white cocoon. Offspring all zebra larvæ; cocoons of several shades from yellowish salmon to strong golden yellow.

A male starveling, Bagdad, white larva, white cocoon, mated with female, vigorous, Italian Salmon, zebra larva, salmon cocoon. Offspring all zebra larvæ; cocoons 78 white and 71 salmon.

A male, vigorous, Italian Salmon, zebra larva, salmon cocoon, mated with female starveling, Bagdad, white larva, white cocoon. Offspring all zebra larvæ; cocoons 63 white and 65 salmon to yellowish salmon.

A male, vigorous, Italian Salmon, zebra larva, salmon cocoon, mated with female starveling, Bagdad, white larva, white cocoon. Offspring all zebra larvæ, cocoons $\frac{1}{2}$ salmon and $\frac{3}{4}$ white.

From these matings and results it seems obvious that what determines the behavior in inheritance of a character, that is, what determines its prepotency or lack of prepotency, its dominance or recessiveness, is something fully apart from (a) sex of the parent and (b) physical vigor of the parent. In all the above matings the larval character zebra striping is regularly dominant in all lots, whether the parent representing the zebra larval characteristic be male or female, vigorous or weak bodied.

STRAIN AND INDIVIDUAL IDIOSYNCRASIES.

In numerous conversations with Luther Burbank the distinguished plant-breeder of Santa Rosa, California, I have heard a certain phrase fall often from his lips. Many years of close observation and of extraordinarily wide experimentation in inheritance have deeply impressed on Burbank the actuality of "individual idiosyncrasy" in the matters of heredity. And I use this term as expressing what I believe actually to exist in the case of the silkworms. Coupled with it I use also the phrase "strain idiosyncrasy" to indicate a varying inheritance behavior of certain characteristics according to races or strains of long breeding.

These phrases are not used to obscure explanation or to relegate the matter to hopeless confusion—there is of course regularity at the bottom somewhere—but are used because no generalization or law of inheritance so far formulated seems to offer an expression or explanation sufficiently defining the actual phenomena or order of inheritance as exhibited by the silkworms (and by other animals).

As examples of the condition described as "individual idiosyncrasy," we may take the following:

♂ Bagdad pure race, white larva, white cocoon X ♀ Italian Salmon, pure race, tiger-banded larva, salmon cocoon; produced 135 tiger-band, 129 white larvæ, and all salmon cocoons.

♂ Italian Salmon pure race, tiger-banded larva, salmon cocoon, X ♀ Bagdad pure race, white larva, white cocoon; produced all tiger-band larvæ, and all white cocoons.

♂ Bagdad pure race, white larva, white cocoon, X ♀ Italian Salmon, pure race, tiger-banded larva, salmon cocoon; produced all tiger-band larvæ and 78 white cocoons and 71 salmon.

Now the differences in the larval inheritance in these three first cross rearings are explicable on the basis of the Italian Salmon parent having been a homozygote (as regards the larval characteristic) in two cases and a heterozygote in one. But the differences in cocoon character inheritance are not to be so explained.

In the F_2 generations from intermated hybrids of these rearings the larvæ in all cases (except white X white) segregated according to parental characters and did so in Mendelian proportions; the cocoons also segregated according to the parental characters and also did so in most cases with some approximation to Mendelian proportions.

Now to illustrate "strain idiosyncrasy."

Mating Istrian, golden-yellow cocoon, with Chinese White, pure white cocoon race, produced all golden-yellow cocoons; also mating Istrian with Japanese White, pure white cocoon race, produced all golden-yellow cocoons; but mating Istrian with Bagdad pure white cocoon race produced (in some instances) all white cocoons. In fact although the cocoon character of most white cocoon races is recessive in matings with the yellow, green or salmon colors of other races, the white cocoon character of the Bagdad race is dominant in most crossed race matings.

The importance of this matter of a difference in inheritance behavior of the same characteristic in different strains and in different individuals of the same strain leads me to offer in some detail an account of the data obtained from several series of rearings. These data will reveal also certain irregularities in the inheritance behavior which make it difficult or impossible for me to accept Toyama's sweeping conclusions as to the rigorous alternative and Mendelian or in any way thoroughly consistent behavior of the silkworm cocoon colors. In fact my whole work disposes me to be very chary of accepting too quickly the fascinating generalizations concerning the simplicity or rigorous regularity of inheritance behavior. There is no doubt in the world that the Mendelian discoveries and conclusions are a great step forward in our understanding of inheritance phenomena. That they are as widely or as rigorously applicable as some Mendelian disciples assume I doubt very much.

Data of a series of crossings between Bagdad, pure race, bluish-white larva, white cocoon, and Istrian, pure race, clayey-white larva, golden-yellow cocoon.

F₁ ♂ Istrian X ♀ Bagdad; produced all golden-yellow cocoons.

F₂ Hyb. yellow X hyb. yellow; produced 64 yellow, 24 white cocoons.

F₂ Hyb. yellow X hyb. yellow; produced 61 yellow, 28 white cocoons.

F₁ ♂ Bagdad X ♀ Istrian; produced all white cocoons.

F₂ Hyb. white X hyb. white; produced 77 white, 17 yellow cocoons.

F₂ Hyb. white X hyb. white; produced 62 white, 15 yellow cocoons.

F₁ ♂ Bagdad X ♀ Istrian; produced 31 white, 21 yellow cocoons.

F₂ Hyb. white X hyb. white; produced 57 white, 31 yellow cocoons.

F₂ Hyb. white
33 yellow cocoons.

In the above series there is a striking combination of alternative inheritance in Mendelian manner with marked individual idiosyncrasies. At first glance these idiosyncrasies seem to depend on sex-dominancy but an inspection of the F_2 generations will show that sex is not the determinant of dominancy.

Data of a series of crossings between Italian Salmon, *zebra larva, pinkish yellow (salmon) cocoon race and Bagdad, white larva, white cocoon race.

F_1 ♂ Ital. Sal. X ♀ Bagdad; producing all zebra larva, and cocoons varying from dirty white through salmon, pale straw yellow to golden yellow.

F_1 ♂ Bagdad X ♀ Ital. Sal; producing 133 zebra, and 129 white larvæ; all salmon cocoons.

F_2 ♂ Hyb. zebra larva, salmon cocoon, X ♀ hyb. white larva, salmon cocoon; producing 35 zebra larvæ spinning 17 salmon to yellow and 3 white cocoons, and 26 white larvæ, spinning 11 pale salmon to yellow and 4 white cocoons.

F_2 ♂ Hyb. white larva, salmon cocoon, X ♀ zebra larva, salmon cocoon; produced 30 zebra larvæ spinning all salmon to yellow cocoons, and 33 white larvæ spinning 18 salmon to yellow cocoons.

F_2 ♂ Hyb. white larva, salmon cocoon, X ♀ hyb. zebra larva, salmon cocoon; produced 48 zebra larvæ spinning 13 salmon to yellow and 9 white cocoons, and 36 white larvæ spinning 17 pale salmon to yellow and 6 white cocoons.

F_2 Hyb. white larva, salmon cocoon, X hyb. white larva, salmon cocoon; produced all white larvæ, spinning 25 salmon to yellow and 7 white cocoons.

F_1 ♂ Ital. Sal. X ♀ Bagdad; produced all zebra larvæ and all white cocoons.

F_2 Hyb. zebra larva, white cocoon, X hyb. zebra larva, white cocoon; produced 46 zebra larvæ spinning 27 white and pale salmon cocoons, and 15 white larvæ spinning 10 white and 2 pale salmon cocoons.

F_2 Hyb. zebra larva, white cocoon, X hyb. zebra larva, white cocoon; produced 40 zebra larvæ spinning 12 white and 5 salmon cocoons and 7 white larvæ spinning 2 white and 1 salmon cocoons.

* Italian Salmon race has two discontinuous types of larvæ, viz., Zebra and White, but where the race name is used without qualification I refer always to Zebra type.

F₁ ♂ Ital. Sal. X ♀ Bagdad; produced all zebra larvæ and all yellowish salmon to golden yellow cocoons.

F₂ Hyb. zebra larva, salmon-yellow cocoon X hyb. zebra larva, salmon-yellow cocoon; produced zebra larvæ spinning 19 white and 19 salmon to yellow cocoons, and white larvæ spinning 4 salmon to yellow cocoons.

F₂ Hyb. zebra larva, salmon-yellow cocoon X hyb. zebra larva, salmon-yellow cocoon; produced 68 zebra larvæ spinning 14 white and 38 salmon to yellow cocoons, and 26 white larvæ spinning 2 white and 12 salmon to yellow cocoons.

F₁ ♂ Bagdad X ♀ Ital. Sal.; produced all zebra larvæ and 78 white and 71 salmon cocoons.

F₂ Hyb. zebra larva, white cocoon X hyb. zebra larva, white cocoon; produced 96 zebra larvæ spinning 73 white and 23 salmon cocoons and 26 white larvæ spinning 4 white and 1 salmon cocoons.

F₂ Hyb. zebra larva, white cocoon X hyb. zebra larva, white cocoon; produced 108 zebra larvæ spinning 58 white and 20 very pale salmon to light yellow-salmon cocoons, and 40 white larvæ spinning 22 white and 8 pale salmon cocoons.

F₂ Hyb. zebra larva, white cocoon X hyb. zebra larva, white cocoon; produced 125 zebra larvæ spinning 64 white and 16 salmon cocoons, and white larvæ spinning 15 white and 72 salmon cocoons.

F₂ Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 105 zebra larvæ spinning 9 white and 55 pale to yellow salmon cocoons, and 67 white larvæ spinning 17 white and 50 pale to yellow salmon cocoons.

F₂ ♂ Hyb. zebra larva, white cocoon X ♀ hyb. zebra larva, yellow cocoon; produced 97 zebra larvæ spinning 25 white and 24 salmon cocoons, and 20 white larvæ spinning 7 white and 9 salmon cocoons.

F₂ ♂ Hyb. zebra larva, white cocoon X ♀ hyb. zebra larva, yellow cocoon; produced zebra larvæ spinning 60 white and 45 salmon cocoons, and 35 white larvæ spinning 14 white and 17 salmon cocoons.

F₂ ♂ Hyb. zebra larva, yellow cocoon X ♀ hyb. zebra larva, white cocoon; produced 140 zebra larvæ spinning 40 white and 63 salmon cocoons, and 68 white larvæ spinning 21 white and 28 salmon cocoons.

F₁ ♂ Ital. Sal. X ♀ Bagdad; producing all zebra larvæ and 63 white and 65 salmon to yellow (20 really yellow) cocoons.

F₂ Hyb. zebra larva, yellow cocoon X hyb. zebra larva, yellow cocoon; produced zebra larvæ spinning 21 white and 81 salmon to yellow cocoons, and 47 white larvæ spinning 8 white and 20 salmon to yellow-salmon cocoons.

F₂ Hyb. zebra larva, yellow cocoon X hyb. zebra larva, yellow cocoon; produced 45 zebra larvæ spinning 6 white and 12 salmon to yellow cocoons, and 18 white larvæ spinning 3 white and 15 salmon to yellow cocoons.

F₂ Hyb. zebra larva, white cocoon X hyb. zebra larva, white cocoon; produced 66 zebra larvæ spinning 54 white cocoons and 17 white larvæ spinning 4 white and 1 pale salmon cocoons.

F₂ Hyb. zebra larva, white cocoon X hyb. zebra larva, white cocoon; produced 10 zebra larvæ spinning 3 white and 1 salmon cocoons, and 3 white larvæ spinning 1 white cocoon.

F₁ ♂ Ital. Sal. X ♀ Bagdad; produced all zebra larvæ and 11 white and 5 yellow-salmon cocoons.

F₂ Hyb. zebra larva, white cocoon X hyb. zebra larva, white cocoon; produced 158 zebra larvæ spinning 83 white and 35 pale salmon cocoons and 43 white larvæ spinning 26 white and 6 pale salmon cocoons.

F₁ ♂ Bagdad X ♀ Ital. Sal.;
produced all zebra larvæ and 78
white and 71 salmon cocoons.

♂ Ital. Sal. X ♀ Bagdad; pro-
duced all zebra larvæ and 63
white and 65 salmon cocoons.



F₂ Hyb. zebra larva, white
cocoon

X hyb. zebra larva, white cocoon;
produced 88 zebra larvæ spinning 43 white and 10 pale
salmon cocoons, and 16 white larvæ spinning 10 white and
5 pale salmon cocoons.

F₂ Hyb. zebra larva, white
cocoon

X hyb. zebra larva, white cocoon;
produced 98 zebra larvæ spinning 68 white and 21 pale
salmon cocoons, and 39 white larvæ spinning 19 white and
10 pale salmon cocoons.

- F₂ Hyb. zebra larva, white cocoon X hyb. zebra larva, white cocoon; produced 112 zebra larvæ spinning 77 white and 19 pale salmon cocoons, and 51 white larvæ spinning 13 white and 4 pale salmon cocoons.
- F₂ Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 85 zebra larvæ spinning 14 white and 38 salmon to yellow cocoons, and 26 white larvæ spinning 3 white and 21 salmon cocoons.
- F₂ ♂ Hyb. zebra larva, yellow cocoon X ♀ hyb. zebra larva, white cocoon; produced 99 zebra larvæ spinning 34 white and 28 pale salmon to salmon cocoons, and 37 white larvæ spinning 14 white and 19 salmon cocoons.
- F₂ ♀ Hyb. zebra larva, white cocoon X ♂ hyb. zebra larva, yellow cocoon; produced 227 zebra larvæ spinning 63 white and 68 pale to yellow salmon cocoons, and 47 white larvæ spinning 20 white and 27 pale to yellow salmon cocoons.

A few examples from other Bagdad X Italian Sal. series may be given to emphasize the actuality of individual idiosyncrasies in these crossings.

- F₁ ♂ Ital. Sal. X ♀ Bagdad; produced 50% zebra and 50% white larvæ, and all white cocoons.
- F₂ Hyb. zebra larva, white cocoon X hyb. zebra larva, white cocoon; produced 43 zebra and 11 white larvæ and 38 white and 9 salmon to golden yellow cocoons.
- F₂ ♂ Hyb. white larva, white cocoon X ♀ hyb. zebra larva, white cocoon; produced 61 zebra and 59 white larvæ, and 67 white and 20 salmon cocoons.
- F₁ ♂ Bagdad X ♀ Ital. Sal.; produced all zebra larvæ and all white cocoons.
- F₂ Hyb. X hyb.; produced 68 zebra and 42 white larvæ and 44 white and 19 salmon to golden cocoons.
- F₂ Hyb. X hyb.; produced 114 zebra and 26 white larvæ and 36 white and 9 salmon cocoons.
- F₁ ♂ Bagdad X ♀ Ital. Sal.; produced 58 zebra and 73 white larvæ, and all white cocoons.

- F_2 Hyb. zebra larva, white cocoon X hyb. zebra larva, white cocoon; produced 37 zebra and 14 white larvæ, and 23 white and 2 salmon cocoons.
- F_1 ♂ Bagdad X ♀ Ital. Sal.; produced 50% zebra and 50% white larvæ and all salmon cocoons.
- F_2 Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 75 zebra and 16 white larvæ and 16 white and 45 pale salmon to golden yellow cocoons.
- F_2 ♂ Hyb. zebra larva, salmon cocoon X ♀ hyb. white larva, salmon cocoon; produced 52 zebra and 42 white larvæ, and 21 white and 59 salmon to golden cocoons.
- F_2 ♂ Hyb. white larva, salmon cocoon X ♀ hyb. zebra larva, salmon cocoon; produced 63 zebra and 78 white larvæ, and 21 white and 57 salmon to golden cocoons.
- F_1 ♂ Bagdad X ♀ Ital. Sal.; produced 50% zebra and 50% white larvæ and all salmon to yellow cocoons.
- F_2 ♂ Hyb. zebra larva, salmon cocoon X ♀ hyb. white larva, salmon cocoon; produced 43 zebra and 40 white larvæ, and 22 white and 39 salmon to golden cocoons.
- F_2 Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 123 zebra and 44 white larvæ and 27 white and 109 salmon to golden cocoons.
- F_2 Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 122 zebra and 15 white larvæ and 33 white and 91 salmon to golden cocoons.
- F_2 ♂ Hyb. zebra larva, salmon cocoon X ♀ hyb. white larva, salmon cocoon; produced 83 zebra and 66 white larvæ, and 19 white and 99 salmon to golden cocoons.
- F_1 ♂ Bagdad X ♀ Ital. Sal.; produced 60 zebra and 45 white larvæ and all salmon to yellow cocoons.
- F_2 Hyb. zebra larva, salmon cocoon X hyb. zebra larva, golden cocoon; produced 85 zebra and 22 white larvæ and 6 white and 47 salmon to golden cocoons.
- F_1 ♂ Ital. Sal. (white larva) X ♀ Bagdad; produced all white larvæ and 9 white and 15 salmon yellow cocoons.
- F_2 Hyb. white larva, salmon cocoon X hyb. white larva, salmon cocoon; produced all white larvæ, and 5 white and 16 salmon to yellow cocoons.

- F₂ Hyb. white larva, salmon cocoon X hyb. white larva, salmon cocoon; produced all white larvæ and 10 white and 22 salmon to golden-yellow cocoons.
- F₁ ♂ Bagdad X ♀ Ital. Sal.; produced all zebra larvæ and 19 white and 35 salmon to yellow cocoons.
- F₂ Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 73 zebra and 28 white larvæ and 47 white and 38 salmon to golden-yellow cocoons.
- F₂ ♂ Hyb. zebra larva, salmon cocoon X ♀ hyb. zebra larva, white cocoon; produced 156 zebra and 39 white larvæ and 59 white and 61 salmon to yellow cocoons.
- F₂ Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 123 zebra and 55 white larvæ and 17 white and 99 salmon to golden cocoons.
- F₂ Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 50 zebra and 15 white larvæ and 17 white and 44 salmon to golden cocoons.
- F₂ Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 60 zebra and 19 white larvæ and 15 white and 45 salmon to golden cocoons.
- F₂ Hyb. zebra larva, salmon cocoon X hyb. zebra larva, salmon cocoon; produced 34 zebra and 17 white larvæ and 19 white and 26 salmon to golden cocoons.

In these series are to be noted the regularly Mendelian behavior of the larval patterns (in many of the lots the numbers were either so reduced by disease or by the necessities of space, food and time of care-takers as to obscure the Mendelian proportions), the marked individual idiosyncrasies (reversal of dominance, splitting of colors equally in first crosses, impure recessive behavior in second (hybrid) generations, etc., etc.) in the cocoon color inheritance, the constant tendency for the salmon color to break into a series of graduating colors ranging from the very pale salmon through to strong (golden) yellow, and the influence of white toward making the salmon extremely pale, i. e., to produce a blending in inheritance rather than a sharp segregation. But the cocoon color does not always behave irregularly. In many cases it behaves in almost exact Mendelian manner, and this is true whether in F₁ the dominant color is salmon yellow or is white. In F₂ lots the splitting will then be respectively 3 salmon-yellow to 1 white or 3 white to 1 salmon-yellow, which

very regularity only emphasizes more the reality of individual idiosyncrasies in such cases of reversed dominance.

While white cocoon color is in most race crossings recessive in character, it is, as already pointed out, not so in all crossings of white and colored cocoon races. For example Bagdad race (white cocoon) seems to be an especial vigorous or potent race in race crossings, the white cocoon color being frequently dominant. Examples of this have already been given. In addition Italian White (white cocoon) crossed with Galbin Italiano (salmon-yellow cocoon) gives young all spinning white cocoons and in F_2 lots the two colors segregate in Mendelian proportions. In these crossings we have examples (asked for by Bateson in his summing up of the "progress of genetics since the rediscovery of Mendel's papers," p. 389, *Progressus Rei Botanicae*, vol. 1, 1907) of two whites producing a color. That is the color is carried germinally through an all white F_1 to appear in F_2 .

In some matings with this same Galbin Italiano salmon-yellow cocoon race a reversal of the above described condition occurred. For example Galbin Italiano crossed with Bagdad (in many crossings a prepotent race and almost always stronger than Japanese White) showed in F_1 a dominance of the salmon-yellow cocoon color which in F_2 lots split in Mendelian proportions.

Despite the inconsistencies in dominant-recessive relation between the cocoon color exhibited in the foregoing data the faithfulness to the alternative character of the inheritance (except in the matter of the break-down of salmon into all the shades from very pale salmon to strong golden yellow) and the adherence or approximation to Mendelian numerical proportions are striking. But these two features have also their marked exceptions in other series of crossings.

In mating Bagdad white cocoon race with Japanese green cocoon race white, greenish white, green, greenish yellow and yellow cocoons are got in the first generation.

In mating Bagdad white cocoon race with Persian lemon yellow cocoon race, green and strong yellow cocoons are got in the first generation. In mating Italian Salmon, pale pinkish yellow or salmon cocoon race, with Istrian, strong golden yellow cocoon race, cocoons of all gradations from salmon to golden are got in the first generation, and also in the second generation whatever two cocoon shades be mated together. In mating Italian Salmon and Chinese White, in first, and especially in later generations, there is a strong tendency for all sharp distinction between white and salmon to break down and cocoons

are got representing a continuous series of gradations from white up to well-marked salmon, the whitish and pale salmon shades being most abundant. But not always! As for example:

F₁ Italian Salmon X Chinese White; produced 60 zebra and 60 white larvæ and cocoons ranging from very pale to strong salmon.

F₂ Hyb. X hyb.; produced very pale salmon cocoons.

F₂ Hyb. X hyb.; produced 31 creamy to salmon cocoons.

F₂ Hyb. X hyb.; produced 38 whitish to salmon cocoons.

F₂ Hyb. X hyb.; produced 31 salmon cocoons.

F₂ Hyb. X hyb.; produced all salmon to strong yellowish salmon cocoons.

And repeated groups of F₂ generations varied among themselves although the parents of all the members of each group were brothers and sisters (i. e., all from a single F₁ lot). But in the large majority of lots the break-down was complete and the cocoons ran continually from white to salmon, with the modal shade a very pale salmon.

Conclusions.—Not to prolong unduly this discussion an end may be made of the presenting of data. The evidence could be piled high by introducing the details of other series of rearings, but this seems to me unnecessary.

It seems plain to me that the inheritance of the cocoon color character is not a consistent one. The characteristic may behave in strictly alternative and nearly exact Mendelian manner. Or it may be inconsistent as to dominance within the same races; that is of a pair of allelomorphs one may be dominant in one cross mating and the other dominant in a second cross mating between the same races. While in a third cross mating between the same pure races neither cocoon color may be dominant but half or another proportion of the offspring may be of one color and the rest of the other color. Or the color characters may not behave as a strictly alternative character but may blend or break down in transmission.

These variants or deviations from a strictly alternative Mendelian character may appear within the same race crossings and even within a single group of F₂ and F₃ generations, all derived from a common parental or grand-parental crossing, or these deviations may be characteristic of crossings between different races or strains possessing similar cocoon color. In the first place the deviations or inconsistencies in inheritance behavior may be attributed to "individual idiosyncrasies"; in the second to "strain idiosyncrasies."

The condition is different in the case of the larval characters. Here the inheritance behavior is consistent, is rigid. It can be prophesied. It follows the Mendelian principles of alternative inheritance with great fidelity.

What is the reason for this difference between the inheritance behavior of the larval characters and that of the cocoon characters? What is the significance of this difference?

In the five thousand years or less during which the mulberry silkworm has been the subject of man's ameliorating attention the principal aim of all the manipulation by the various processes involved in artificial selection has been the modification of the cocoon characteristics. The attempt has been to produce more silk, better silk, silk of one color, silk of another color. As regards larval and imaginal characters, much less attention and manipulation have been given. Docile, disease-resistant and hearty-feeding larvæ, prolific and sedentary moths have been encouraged by selection. But larval patterns, diverse and distinct though they appear to us today, have not been the product of the breeder's work except as they may be correlated with valuable cocoon characters and thus preserved by the way. The diversity in larval pattern is a natural diversity; the differences have appeared and have persisted according to natural processes.

Not so with the cocoon characters. Or at least only in so far as natural variation has coincided with the breeder's wishes. The cocoon colors have originated as fluctuating variations fostered, accumulated, and fixed by careful, rigorous selection. Or if any of them have appeared as discontinuous variations or sports they have been given from the start all the advantage of the breeder's selective attention.

But the larval patterns have had to make their way alone. How have they come to exist then? As fluctuating variations fostered and fixed by selection? No; for neither artificial selection (except in rare possible cases of coincidence with a desirable cocoon variation), nor natural selection have played any part in their history in the last 4000 or 5000 years. Then they have probably arisen as discontinuous variations or sports, or as mutations, if the mutationists will admit them to their charmed circle. But in order to persist, these discontinuous larval variations or sports must have been endowed with a certain potency or prepotency, which prevented them from being lost or extinguished by interbreeding. If these discontinuous variations, sports, or mutations, have arisen, as seems probable from the analogy with other discontinuous variations, in small numbers, then the per-

sistence and final definite establishment of these larval characteristics must have been due to a potency in inheritance at least equivalent to that shown by such discontinuous variations as De Vries's mutations.

There is an important significance then, to my mind, in this difference of conditions between the cocoon characteristics and the larval characteristics of the silkworm. On the one hand we have different characteristics appearing originally, in most cases at least, as slight fluctuating or Darwinian variations, selected, fostered and fixed by the careful attention and manipulation of the breeder and by these means finally elevated to a condition apparently stable and of value equivalent to that of the usual differences in natural races or species. On the other hand we have, in the larval characteristics, a series of differences or variations which are strictly natural in their establishment. This establishment however cannot have come about by selection; not by natural selection, because during the many generations in the course of which this establishment has been brought about, the silkworm has not been exposed to natural selection; not by artificial selection, probably, because the characteristics are of no interest to the breeders. The establishment has come about, then, through natural methods, probably by the appearance of sudden discontinuous variations or mutations, which have been sufficiently potent in inheritance to have maintained themselves.

Despite this difference in the method of establishment the two sets of characteristics appear now on their faces to be of equivalent character and worth. But an experimental study of them by a protracted series of matings, pure and cross, shows that they are not of equivalent worth. The larval characteristics, established by Nature, are unbreakable, behave consistently and rigorously in inheritance through all possible manipulation. The cocoon characteristics, established artificially, break down under manipulation, are inconsistent in their inheritance behavior and reveal an instability which distinguishes them clearly and importantly from the larval characteristics.

And yet there are important and suggestive points of likeness. The cocoon characteristics as they stand today are discontinuous in their nature and show a strong tendency to become fixed, stable and consistent in inheritance, this stability and consistency being exactly of the type shown by the larval characteristics. In many crossings the cocoon characteristics are inherited in purely alternative manner and with close approximation to Mendelian proportions. In other crossings, using the same characteristics in different strains or races, or,

perhaps, indeed, within the same strains, the Mendelian behavior is lost, and even the discontinuous or alternative nature of the characteristics breaks down.

These different conditions displayed by the inheritance of larval and cocoon characters are to my mind extremely suggestive. They seem to me to indicate pretty clearly strong differences between naturally established and artificially established characters; they seem to indicate the difficulty of explaining fixed strain, race and species differences on the basis of selection of fluctuating variations; they seem to point toward explanation of such differences on the basis of discontinuous variations or mutations; but they seem, finally, to indicate an essential likeness, at bottom, between characteristics established by the selection of fluctuation variations and characteristics established by the appearance, full-fledged, of potent discontinuous variations. The differences established by the selection of fluctuating variations seem to require a long period of time to get upon that safe ground of independence which is attained almost at once by the difference established by discontinuous variations or mutations. And yet the fact seems plain that in a long time both kinds of differences will come to rest upon and be possessed of the same inheritance behavior and potency.

DOUBLE MATING.

In connection with the question of prepotency of strain or race in cross mating, experiments have been begun in double mating, that is in pairing a female of one race with two (or more) males representing two different races. The silkworm is polygamous, both males and females usually mating more than once before egg-laying begins. Or this repeated mating may continue after egg-laying has begun.

In any consideration of the results of such repeated mating the unusual way in which the eggs of insects (at least of the silkworm moth and hosts of others) are fertilized must be remembered. This way is, simply, that the male fertilizing cells, the spermatozoa, are received by the female at mating into a special sac or receptacle, the spermatheca (there may be several spermathecae, as in flies) in which the spermatozoa remain alive and active. This spermatheca, a diverticulum of the oviduct, is situated near its external opening, the vagina. As the unfertilized eggs of the moth pass slowly down from the ovarian tubes into the oviduct they lack only fertilization to be entirely ready for development. They have already their full supply of yolk, they are already enclosed in their protecting envelopes (vitelline membrane and outer, firmer chorion). But these envelopes do not *completely* enclose the egg-mass; there is, at one pole of the egg, one or more small openings, the micropyle, through which the spermatozoa, issuing from the duct of the spermatheca as the eggs pass, enter the eggs. As soon as a single spermatozoan has entered, a jelly-like substance closes the micropyle and prevents polyfertilization.

Thus when the silkworm moth first mates she receives in her spermatheca, and holds there, a considerable number of spermatozoa representing the heritable characters of the male involved. When she couples again she receives another lot of spermatozoa, and if the second coupling is with a male of different race from the first these spermatozoa represent a new set of characters. What is going to be the result of this double mating as exhibited in the offspring?

In 1905 a female of Japanese White race (white patterned larva, white constricted cocoon) was mated with a male of the same race and allowed to lay some eggs and was then mated again, this time with a male of Italian Salmon (from a zebra larva) and allowed to lay another lot of eggs. All the larvæ (1906 rearings) from both sets of eggs

were of Japanese White race type, as were also all the cocoons spun by these larvæ.

In 1906 several double matings were made but in a different way. The female was not allowed to lay eggs after the first mating but was immediately, after the first mating, remated with a male of different race, then allowed to lay all of her eggs, and the offspring got in 1907 from these double matings all reared through to maturity, and their characters, larval and pupal, noted and tabulated. The matings and results were as follows:

(No. 111.) Female Bagdad (white larva, white cocoon) was mated with a male Bagdad and then with a male Istrian (buffy larva, golden yellow cocoon). Result, all the young were of Istrian larval type and of Bagdad cocoon type. Too much stress cannot be laid upon the larval type because the Bagdad and Istrian larvæ are much alike, although the noticeable clayey or buffy tinge of the Istrian larvæ is really a fairly distinguishing character.

(No. 112.) Female Bagdad mated with male Bagdad and then with male Istrian. Result, eggs all sterile; no hatches.

(No. 113.) Female of Italian Salmon (white larva, pink yellow cocoon) mated with male of same race and then with male Bagdad (white larva, white cocoon.) Result, all white, i. e., Bagdad cocoons.

(No. 236.) Female of Japanese Green race (white larva, green cocoon) mated with male Bagdad (white larva, white cocoon) for 1½ hrs., then with male Istrian (clayey-white larva, golden-yellow cocoon) for a longer time. Result, all golden-yellow, i. e., Istrian cocoons.

(No. 238.) Female of Bagdad race (white larva, white cocoon) mated with male Istrian (clayey-white larva, golden-yellow cocoon) for 1½ hrs. and then with male Japanese Green (white larva, green cocoon) for a longer time. Result, cocoons all golden yellow, i. e., Istrian.

(No. 239.) Female of Bagdad race (white larva, white cocoon) mated with male Japanese Green for 1½ hrs., then with male Istrian (clayey-white larva, golden-yellow cocoon) for a longer time. Result, all cocoons golden-yellow, i. e., Istrian.

These few experiments (the subject is being followed up more extensively this year) show that in such double matings one strain is potent over another. With two kinds of spermatozoa in the spermatheca, fertilization of the eggs does not occur according to the laws of probability, but the spermatozoa of one strain are successful in the race

or struggle to fertilize, or in some other way control the development of the egg. And the race that is potent in these mixed matings may be the one possessing those characters which are dominant in the Mendelian sense in cross matings. That is the yellow cocoon color represented by the Istrian race in several double matings where the Istrian male is either the first or second in mating, where his coupling time is either the shorter or the longer, is dominant in each case over the white cocoon color represented by the Bagdad female or male and over the green cocoon color represented by the female or other male (Japanese Green) involved in the double mating. (See lots numbered 236, 238, and 239.)

But in lots 111 and 113 we have a potency on the part of the Bagdad race, represented in one case by the female and one of the males, in the other by only one of the males, which does not correspond to any dominancy on the part of the character, i. e., white cocoon color, which reveals this potency. In both these double matings, Italian Salmon being the other race involved, the offspring all spun white cocoons. But in simple cross matings of pinkish-salmon cocoon-color with white cocoon-color, white is usually the recessive character. Hence dominancy of character does not explain the results obtained in lots 111 and 112.

But confirmatory matings are necessary before accepting the results of lots 111 and 112 as something regularly to be expected under similar conditions of mating. As I have already said the work is being more extensively carried on, and will be reported on in the future.

FLUCTUATING VARIATIONS AND THEIR INHERITANCE.

While such characters as larval pattern and cocoon color seem to be essentially discontinuous in their appearance and alternative in inheritance, certain other silkworm characters are distinctly fluctuating or continuous in variation and non-alternative in inheritance. Such characters are amount and quality of silk thread composing the cocoon, shape of the cocoon, wing-pattern of the adults, wing-venation, certain larval markings subsidiary to the whole condition of color pattern, degree of adhesiveness of the eggs, polyvoltinism, etc.

A good deal of laborious work was done in the first three years of the six over which our experimental rearing has extended, in connection with these continuous or fluctuating variations. But little space, however, need be given to stating the results of the work.

Coutagne has already shown the strictly fluctuating character of the differences in "*richesse de soie*," which may be taken as including the quantity and quality of the silk. His series of rearings from matings based on a careful selection as regards the character extend over ten years and show clearly the variational and inheritance behavior of the characteristic. It is strictly continuous, fluctuating, and non-alternative.

For a knowledge of the behavior in variation and inheritance of the characteristic, shape of cocoon, Coutagne and Toyama's work is sufficient. They both show it to be fluctuating as to variation and non-alternative as to inheritance.

Toyama has worked also on the character polyvoltinism, or, better expressed, the brood character of the silkworm, whether of annual generation, or of two or more generations a year, expressed by silk-growers as univoltine, divoltine, multivoltine. He finds it to be a fluctuating character, to be maintained in one condition only by rigorous selection. "Thus," he writes, "when we crossed a multivoltine with univoltine breed, the eggs laid by the moth were either pure maternal or pure paternal, very rarely a mixture of both parents. Those forms raised from the first cross do not remain true to the parents in subsequent generations. Even when we selected multivoltine parents for five generations, we failed to get any constant multivoltine breed." Miss McCracken has carried on and still is maintaining in our labora-

tory an elaborate study of the inheritance behavior of this character and will report on her work in another year.

My own observations and experimental rearings on these various fluctuating characteristics touch especially the following: degree of adhesiveness of the eggs; subsidiary larval markings within the so-called "white" and "patterned" types (which behave as a whole in discontinuous and alternative fashion); wing pattern, and finally wing venation. I shall discuss these characteristics briefly in the order in which they have just been named.

INHERITANCE OF EGG CHARACTER.

The eggs of different silkworm races show differences apparently constant in size, color and shape. But none of these differences has seemed to me quite marked enough to be used in my studies; at any rate no attempt has so far been made to study the inheritance behavior of any of these characters.

But the character of adhesiveness (or lack of adhesiveness) is so conspicuous and so readily and certainly determinable that it has been made the subject of some experimental breeding. The one race in my possession whose eggs are regularly (this regularity is not absolute) non-adhesive is the Bagdad race, a strong white larva and white cocoon race much used in the laboratory. Females of this race simply drop the "non-sticky" eggs loosely in the mating boxes (small oblong boxes made by folding and pinning square sheets of strong paper in which the male and female to be mated are confined and in which the female deposits her eggs). These loose eggs are like so many little spherical seeds, yellowish at first but soon changing to lead-gray. The eggs of all the other races I have are strongly stuck to the paper of the boxes in a single layer with the eggs close together. Among the races depositing adhesive eggs there is practically no female which fails to fasten its eggs. Of course it would be quite possible for a female of such a race to show the teratological condition of absence of cement glands and such a one could of course not fasten her eggs. But in all our rearings I do not recall a single case of the oviposition of loose eggs by a female of an "adhesive egg" race. But the contrary is not true. That is the females of the Bagdad race, the one non-adhesive egg race that I have reared, show a certain degree of variation in regard to this characteristic. This variation comprises the deposition of eggs actually adhesive, that is fastened to the paper, but only weakly so, that is, they may be displaced by gentle rubbing (it requires

vigorous rubbing to remove eggs of the adhesive egg races). Or in rarer cases the eggs may be fairly firmly fastened. In other cases some eggs may be firmly fastened and some weakly fastened. In others some may be weakly fastened and some loose and the proportion of loose to fastened may be slight to large. But the females showing these variations in the egg character are very few compared with those showing the normal loose eggs condition. Matings were made pure and crossed on the basis of these variations in the egg laying, and the results, although the work has been only fairly begun, already show unmistakably the general character of the inheritance behavior of the characteristic.

This egg character or rather imaginal character of egg-laying is not a Mendelian or alternative character in inheritance. The non-adhesive condition exhibited by the Bagdad race however it may have originated, either as sport or as selected fluctuating variation, shows a plain tendency to change (back?) to the adhesive condition. From those few pure Bagdad matings (out of many pure Bagdad matings made) in which the female laid adhesive eggs, young were obtained which on being mated together produced some adhesive eggs in almost every case, and in most of these cases all the eggs laid were adhesive. From crossed race matings in which the female was a Bagdad laying adhesive eggs, young were obtained which, mated together, produced almost exclusively adhesive eggs. It seems from this plain that the adhesive egg character is very unstable, succumbing quickly in crossed matings to the character adhesiveness, and tending even in pure matings to throw partially or even completely (reversions?) the character adhesiveness.

But when there are mated together hybrids produced by crossing Bagdad with a non-adhesive egg race the young of these hybrids usually lay non-adhesive eggs. That is, this is true in practically all cases where the hybrids have for parents a Bagdad moth and a moth of any one of six other different races used in the matings. But where the parents were a Bagdad moth and a moth of a certain single adhesive egg race, viz., Italian Salmon, the hybrids deposited sometimes non-adhesive, sometimes adhesive eggs.

This character is one exhibited only by the females, of course, but capable of being transmitted through the males. Males of races laying adhesive eggs when mated with Bagdad females (laying non-adhesive eggs) may produce young tending to lay adhesive eggs. In other cases the young from Bagdad males crossed with non-adhesive race

females tend to lay non-adhesive eggs. This is very clear proof of the transmission through the males of this female characteristic as the females of races regularly laying adhesive eggs never tend to sport to non-adhesiveness.

The subject is being further studied and a report will be made later.

SUBSIDIARY LARVAL MARKINGS.

In larvæ of the white type the body is not wholly unmarked but certain markings known in our laboratory under the names of "eyebrows," or "eye-spots," and "anterior and posterior lunules" occur in very faint to fairly strong condition. Lunules occur as a single pair on the dorsum of each of the 2nd and 5th abdominal segments, and the "eyebrows" are markings on the dorsum of the mesothoracic segment. The posterior lunules (on the 5th abdominal segment) correspond externally to the situation of the developing internal reproductive organs (ovaries or testes) and are more elaborate in make-up than the anterior lunules. The "eyebrows" can also be quite elaborate in make-up and when well developed are really of the nature of eye-spots with a colored center, which may be red, yellow or pink, surrounded by purple or blackish lines (see Plates I and II).

All of these markings appear in the so-called "patterned" type of larva (Japanese White race type) and also vary in their degree of conspicuousness, that is, development.

On the basis of these variations in color and degree of development of these larval markings, selection among individuals was repeatedly made, matings instituted on a basis of this selection, and rearings made and all individuals examined and tabulated. The work was laborious and extensive. It was carried on chiefly by Mrs. Bell-Smith.

Her results show clearly the thoroughly continuous and fluctuating character of the variations and the non-alternative character of their inheritance.

WING-PATTERN.

A variation of distinctly fluctuating and continuous character is the wing-pattern of the adult moths. A good deal of attention and time were paid to the variations in wing-pattern through several years, with the result that the purely fluctuating character of the variation and its corresponding non-alternative behavior in inheritance seem certainly established, and hence make any use of it in cross matings of

only subsidiary interest. It is a variation or character strongly subject to Galton's law of regression and does not seem to be capable of any considerable modification or degree of fixation by even a most careful and persistent personal selection.

The pattern consists of the presence, in more or less well-marked condition, of a number of dark curving lines or bars crossing the white or creamy wings from anterior to posterior margin. These lines may be broad and strongly blackish, or narrower and only smoky, or very narrow and faint, or nearly invisible. All gradations from almost total absence of this pattern, when the wing may be called white (W), up to the most marked and elaborate condition of the pattern, when the wing may be called strongly patterned (S. P.) are to be noted. (See figures 1 to 3, Plate II.) For convenience I have established four arbitrary categories or pattern classes, which I call respectively White (W.), Barely Patterned (B. P.), Medium Patterned (M. P.), Strongly Patterned (S. P.). As examples of the manner of inheritance of this variation a short series of lots from the 1906 rearings (from the total series of nearly 300 in which pattern differences were tabulated) may be referred to. The small number of moths representing each lot is due to the fact that not all the cocoons were allowed to give up their moths and that from many that did the moths were allowed to make their condition of pattern undecipherable (by much beating of wings in the small mating boxes) before they were examined for tabulation as to wing-pattern. The records however show plainly the fluctuating and continuous character of the variation, even if the numerical representations of the different pattern types are not capable of being construed as indicating the actual proportions in any whole lot.

(Lot M. 22.) S. P. male mated with W. female. Result, 12 M. P., 5 S. P. and 6 melanic. (Note; male parent was a medium melanic.)

(Lot M. 44.) S. P. male mated with W. female. Result, 7 W., 20 B. P., 11 M. P.

(Lot M. 13.) S. P. male mated with B. P. female. Result, 17 B. P., 5 M. P.

(Lot M. 12.) M. P. male (cream color) mated with M. P. female. Result, 4 W., 13 B. P., 12 M. P., 1 S. P.

(Lot M. 41.) B. P. male mated with S. P. female. Result, 1 W., 3 B. P., 5 M. P., 15 S. P.

(Lot M. 29.) S. P. male mated with B. P. female. Result, 4 B. P., 13 M. P., 3 S. P.

(Lot M. 49.) W. male mated with M. P. female. Result, 1 W., 10 B. P., 11 M. P., 3 S. P.

(Lot M. 42.) M. P. male mated with M. P. female. Result, 18 W., 10 B. P., 11 M. P.

(Lot M. 118.) S. P. male mated with M. P. female. Result, 5 W., 11 B. P., 6 M. P.

(Lot M. 58.) M. P. male mated with W. female. Result, 5 W., 9 B. P., 10 M. P., 1 S. P.

(Lot M. 38.) S. P. male mated with W. female. Result, 4 W., 7 B. P., 10 M. P., 5 S. P. (one of these a melanic).

(Lot M. 45.) S. P. male mated with snowy white female. Result, 1 W., 1 B. P., 4 M. P., 1 S. P.

(Lot M. 27.) S. P. male mated with a pure W. female. Result, 3 W., 1 B. P., 1 M. P.

(Lot M. 52.) S. P. male mated with W. female. Result, 6 B. P., 4 M. P.

(Lot M. 51.) S. P. male mated with W. female. Result, 2 W., 7 B. P., 3 M. P., 2 S. P.

(Lot M. 78.) S. P. male mated with S. P. female. Result, 7 B. P., 5 M. P., 1 S. P. and 1 melanic.

(Lot M. 113.) S. P. male mated with S. P. female. Result, 2 B. P., 1 M. P., 2 S. P.

The S. P. pattern is more common among males than females, but is not confined to either sex.

From these data, the fluctuating and continuous nature of the variation is apparent, and it is equally apparent that there is no alternative character in its inheritance. Rigorous selection would probably be able to produce parents which would throw a larger proportion of S. P. young, and other parents a larger proportion of W. young, but in neither case would this selection probably produce a fixed race. There would simply be produced a condition capable of being maintained as long as vigorous selection was practised, but only so long. This is the probability indicated by my experiments in attempting to foster the extremes of the pattern variation through several generations by selective matings.

WING VENATION.

The variations in the wing venation of a series of silkworm moths constituting a lot of experimental material were studied with a view to seeing whether there are indications of structural degeneration in this

functionally degenerate organ. The material consists of the wings of 52* individuals derived from larvæ which had been subjected to various conditions of feeding as follows:

(Lot 399, sub. 1.) Moths from larvæ fed optimum amount of food during entire experimental history.

(Lot 399, sub. 2.) Moths from larvæ given short rations during a single (the immediate) generation.

(Lot 399, sub. 3.) Moths from larvæ given short rations for one year, optimum for the following (the immediate) generation.

(Lot 399, sub. 4.) Moths from larvæ given short rations during past two generations.

It was thought that upon seriation of the data there might be found some correlation between the variations and the conditions of feeding within each sub-lot. It was realized, however, upon seriation of the data, that while there are certain unique and suggestive variations in certain sub-lots, the series is numerically too short to justify any correlation of variations with conditions of nutrition. Therefore in the following tabulation of results, the variations are seriated for the 52 individuals as a whole, the interest centering in the degenerating structural condition of the venation in this organ which is functionally degenerate through disuse.

Many of the 104 wings exhibit numerous variations from the typical venation (Fig. 1) of the species. These variations may be classified in three groups as follows:

1. Variation by addition of spurs or of short veins to the typical venation.

2. Variation by loss of certain veins in full or in part.

3. Variation by loss of veins proper, i. e., the absence of chitinization combined with the persistence of tracheæ which are disposed:

(a) in such a position as to take the place of veins belonging to the typical venation of today;

(b) along ancient lines of development, as where the extinct base of media is preserved intact in the discal cell.

1. Variations by addition.

The variations classified under this heading are very few numerically and very insignificant in kind, adding but a fractional amount to the total extent of the wing's venation.

* In the 52 pairs of wings some were broken in certain areas so that every study does not include the entire 52 pairs.

Specifically, the variations by addition consist of:

(a) the presence of spurs in unexpected places; such as two short cephalic spurs between the forkings of R_2 and R_{3+4} in a right wing (specimen Sub. 4, H); two longer spurs or short branches running from R_3 near its distal end to the wing's costal margin in 1 right wing (specimen Sub. 1, O); a spur running proximad from R_2 shortly beyond its forking in 1 left wing (specimen Sub. 4, L); a spur originating from the middle of R_4 and running proximad in 1 right wing (specimen Sub. 2, I); a spur originating from the 2nd anal vein and directed toward the inner margin in 1 left wing (specimen Sub. 3, C);

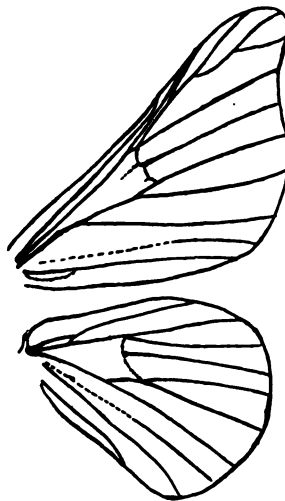


Fig. 1. Venation of the silk-worm moth, *Bombyx mori*.

(b) very short additional cross-veins, as where there is a cross-vein connecting R_3 with R_4 near their distal tips in 1 left wing (specimen Sub. 1, C); or a short cross-vein running cephalad from R_4 to the costal margin in 1 right wing (specimen Sub. 2, I).

2. Variation by loss of certain veins entirely or in part.

The variations are numerous and striking in kind and are represented by many variants. The veins involved include members of the radial, medial and anal series in the fore-wings and the medial, cubital and anal series in the hind-wings.

The variation in the radial series consists of a "continuous" variation on the part of R_4 . This summary included 46 left and 43 right

wings which were perfect and available for study. R_3 is present and normal in 27 of the 46 left wings and in 22 of the 43 right wings. R_3 is *entirely* absent as a separate branch in 29 of the 46 left wings and in 21 of the 43 right wings; R_3 is present in part of its length in three wings as follows: (a) as a very short branch originating typically but ending freely in cell R_2 , $\frac{3}{4}$ of its length from the costal margin, in 1 left wing (specimen Sub. 4, I); (b) as in above under (a) but twice as long in 1 left wing (specimen Sub. 1, B); (c) in three sections, a basal, a terminal, and a middle section lying freely in cell R_2 in 1 right wing (specimen Sub. 1, R).

The variations in the anal series of the fore wings affect the first and third anal veins. In the case of the first anal vein, the variations in 95 wings may be summarized under the following four classes: (a) 4 right and 5 left wings in which there is *not a trace* of the vein; not even a fold, furrow or surviving trachea; (b) 39 right and 33 left wings in which there are faint traces of a thickening or a faintly defined vein distally and not extending for as much as $\frac{1}{2}$ the total length of the vein; (c) 5 right and 2 left wings in which as much as the distal half of the vein is present as a vein, fold, furrow, thickening or trachea or any combination of these; (d) 1 right and 3 left wings in which the distal $\frac{1}{2}$, $\frac{2}{3}$ or $\frac{3}{4}$ of the vein is present as a vein. In no case is the vein found present in its entire length.

The third anal vein is also represented by all stages between and including total absence on the one hand and presence entirely on the other: (a) in 4 right and 2 left wings the vein is absent; (b) in 32 right and 35 left wings the vein is represented in part of its length by a fold, furrow, thickening or surviving trachea or combinations of these; (c) in 4 right and 3 left wings the vein is almost complete; (d) in 7 right and 5 left wings the vein is present in its entirety.

The other variation by loss in the fore wing consists of the absence of the cephalic, caudal, or middle third of the medial cross vein.

In the hind wing the variation by loss of parts concerns the medial, cubital and anal series of veins.

The variation by loss in the medial series of the hind wing consists of an incomplete condition of M_2 : (a) in 1 left wing M_2 is only $\frac{3}{4}$ its normal length, stopping short of the outer margin (specimen, Sub. 1, N); (b) in 1 left wing the chitinization of the base of M_2 is incomplete (specimen Sub. 3, B).

The variation by loss in the cubital series of the hind wing consists

of a single case in which Cu_1 is but $\frac{3}{4}$ its normal length, ending freely short of the outer margin (specimen Sub. 4, 1 left).

The variation by loss in the anal series of the hind wing consists of slight variations in length and character of the first anal vein which, in the typical venation, is incomplete proximally. In 18 right and 20 left wings the distal half of the vein is perfect or normal. This distal portion is in some wings either longer or shorter than $\frac{1}{2}$ the total length of the vein from base of wing to outer margin; in 4 right and 5 left wings, the vein is longer than the normal, while in 14 right and 10 left it is shorter than normal. In 9 right and 8 left wings there is no true chitinization but some part of the vein's distal portion is represented by a thickening, fold or furrow. In 2 right and 2 left wings the vein is $\frac{3}{4}$ its normal length and is continued proximad to the wing's base as a distinct fold. In one pair of wings the vein lies freely in the cell Cu_2 , ending short of both proximal and distal margins of the wing.

The medial cross-vein of the hind wings varies by loss of parts as does its homologue in the fore wings.

The fact that variations by addition are of slight importance (found in only 7 wings and in no case contributing any considerable addition to the venation's total extent) as contrasted with the variations by subtraction or loss of venation in this functionally degenerate organ is suggestive. It would seem to indicate that the variations in this useless organ are characteristically of the nature of a breaking down or degeneration of structures. It is interesting in this connection to compare the conditions in these useless silkworm wings with those found in the highly specialized and useful wings of the honey bees*, in which addition of veins and cells was clearly characteristic of the variation in their venation.

Finally we reach the third group of variations in venation, namely, variation by loss of the chitinization of the veins combined with the substitution of persisting tracheæ where the veins should be. This variation occurs in the 1st and 3rd anal veins and in the discal cell of the fore wings and in M_2 , the medial cross vein, the 2nd anal vein, and the discal cell of the hind wings.

In the fore wing, there are tracheæ in the discal cell in 5 right and 7 left wings, the 1st anal vein is represented by a trachea only in 1 right wing; the 3rd anal vein is represented in part of its length by a trachea

* See Kellogg and Bell, *Studies of Variation in Insects*, Proc. Wash. Acad. Vol. VI, p. 212.

in 20 right and 22 left wings, while in 13 right and 17 left wings the 3rd anal vein is represented by a trachea only.

In the hind wing the medial vein is represented wholly or in part by tracheæ in 4 right wings; in 1 right and 1 left wing the vein M_2 is in part of its length a trachea only; in 1 right wing the 2nd anal vein is a trachea only in its distal portion; there are tracheæ in the discal cell in 1 right and 4 left wings.

In one case (the left hind wing of specimen Sub. 3, I) the tracheæ in the discal cell show an arrangement which might be interpreted as throwing light on the ancient type of venation in the discal cell before it

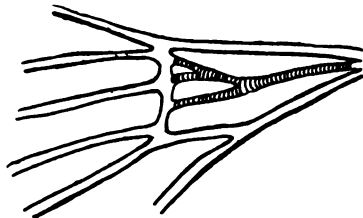


Fig. 2. Diagram showing relation of tracheal trunks to the radial and median veins in the silk-worm moth, *Bombyx mori*.

became a single cell. A single longitudinal trachea arises from the base of the wing and forks at about the center of the cell into two branches (M_{1+2} and M_3). The cephalic branch forks again within the discal cell, separating M_1 from M_2 , while the caudal branch meets and fuses with the medial cross vein until M_3 again turns longitudinally and continues as M_3 distally to the outer margin. (Fig. 2.) It is only within the discal cell that the medial series is represented by tracheæ, the veins of the series being well chitinized outside the discal cell.

To sum up the variations in venation found in these functionally degenerate wings of the silkworm, we find very little variation by addition and no variations in the direction of specialization for a strengthening of the wing skeleton. We find a very large amount of variation by absence of certain veins or by loss of the parts of veins, in some cases the loss being total, in some cases an imperfection in the chitinization and in many cases the survival of tracheæ as substitutes for the missing veins.

This loss of parts of the disused supporting skeleton of the wing is, of course, exactly what we should expect to find in the light of that degeneration of function which has become characteristic of silk-

worm moths. The frequent persistence of tracheæ as the only traces of the last venation suggests that possibly the degeneration of the venation starts with a giving up of the structural features acquired latest in the race's and the individual's development (namely the chitinization which occurs about the tracheæ as trails) and, proceeding backward through time, repeats the story of the structure's birth—by what might be termed a reversed recapitulation of ancestral stages.

MISCELLANEOUS.

DOUBLE COCOONING.

Through all the years of our rearing and in lots representing most of the different races studied the appearance of occasional double cocoons was recorded. By double cocoon is meant a cocoon which is made by the joint labors of two larvæ, the one cocoon enclosing the two pupæ of these larvæ. (See Plate II.) In a few cases triple cocoons, produced by three larvæ working together, occurred. This double cocooning habit is of course a familiar one to silkworm growers and there is even a silkworm race aboriginal to the Riu Kiu Islands described by Sasaki (Bull. Coll. of Agric., Tokyo Imper. Univer., vol. 6, page 33, 1904) in which almost all the cocoons are double. They are large and variable in shape and usually enclose more than two pupæ, not rarely even seven or eight.

Coutagne (*Recherches Experimentales sur l'Hérédité chez les Vers a Soie*, 1902, p. 62 ff) questions whether an increase or decrease in number of double cocoons in a race is really hereditary, i. e., whether it is an acquired racial character, but inclines to hold it to be a purely ontogenetic character depending upon the amount of space available to the spinning worms.

But Duseigneur (*Monog. du Cocon de Soie*, 1875, p. 104) declares that the proportion of double cocoons is in some degree a fairly fixed characteristic of a race. Certain races come up to 30 per cent., in this proportion, while certain others do not get beyond 3 or 4 per cent.

Lambert (*Revue de Viticulture*, 1895, pp. 447) reports on a special Chinese race in which in 8 years he was able to reduce the percentage of double cocoons from 15 per cent. to 3 per cent.

Maillot and Lambert (*Traité sur le Ver a Soie*, 1906, pp. 342, ff) in giving the characteristics of many silkworm races regularly give the percentage of double cocoons, this percentage varying from 2 to 15. Also in their discussion of the effects and results of crossing they quote cases where the proportion of doubles in hybrid races is less than in either parent race. For example in a hybrid race produced by crossing two Chinese parent races the percentum of double cocoons is 1 in place of 2 per centum or 6 per centum characteristic respectively of the parent races. In other cases the proportion of double cocoons in hybrid races is the same as in one of parent races while in others the propor-

tion equals the sum of the parent races, while in still others it is midway between the percentage of the parent races.

All of these data would seem to indicate unmistakably that double cocooning is a heritable condition and not a purely ontogenetic one. They would also indicate that this condition can be fostered or modified by selection and thus made into a racial character.

My own work on double cocooning resolves itself practically into an attempt to foster (or to test) this habit by selection. Experiments were begun in 1902 by mating together a male and female, both of which had issued from the same double cocoon. All the eggs of this mating hatched prematurely except two, the larvæ from which were reared and spun single cocoons. The moths issuing from both these cocoons were both females and were mated one with a male from a double cocoon and one with a male from a single cocoon.

From the general 1903 rearings I collected 9 double cocoons (6 yellows, 3 whites). They varied considerably in shape, the extremes being, respectively, round, elliptical and elongate spindle shaped. In no case was a mixed yellow and white double cocoon found. With the moths from these 9 double cocoons together with some moths from single cocoons, 14 pure and cross matings (on a basis of cocooning habit) were made so as to bring together male moths from double with female moths from double, male moths from single with females from double, and males from double with females from single. Also in mating males and females from double cocoons together care was taken to cross the colors, i. e., a moth from a yellow double would be mated with a moth from a white double. Also pure matings were made in this color respect, thus yellow double with yellow double and white double with white double.

The results of the rearings of the various lots of eggs derived from these matings were as follows:

From 5 lots of eggs with both parents from double cocoons only two double cocoons were obtained, three of these matings producing no double cocoons at all. (These lots were greatly cut down so that comparatively few larvæ were allowed to spin up, but there was plainly no inherited tendency to produce doubles.)

From the matings in which one parent was from a double and the other from a single, 9 matings altogether, only 2 double cocoons were obtained, a single double cocoon appearing in each of two of the lots. (These lots also were very small.)

From a mating made between a moth from a double and a moth

from a single cocoon directly descended from the 1902 mating of doubles, no doubles were obtained.

From a large lot of eggs obtained by allowing three males from doubles to mate miscellaneously with three females from singles, one double and 31 single cocoons were obtained. (This lot was greatly cut down by disease.)

In no cases was a mixed double (i. e., yellow and white) produced.

No matings on a basis of double cocooning condition were made in 1904, but in the 1905 general rearings several double cocoons appeared and from the moths obtained from them 16 matings were made as follows: 11 of double with double (in one case the parents were from the same triple cocoon and in two other cases from the same double); and 5 of double with single. The proportion of doubles to singles produced in 1906 from the 11 1905 matings of double with double was one double to 16 singles, or a little more than 6 per cent. From the mating of the two moths obtained from the same triple cocoon only single cocoons were obtained. From the two matings in each of which both parents were obtained from the same double cocoon, in one case 12 double and 109 single cocoons were got, and in the other no doubles and 57 singles.

In 1907 a few more rearings were made from the eggs produced by the mating in 1906 of moths from double cocoons. In certain of these cases the parents were the offspring of moths which had issued in 1905 from double cocoons. Five of these 1907 rearings represented a second generation of individuals selected on a basis of double cocooning. In three of the cases of these five rearings each pair of parents issued from the same double. And in one of these three cases the grandparents had issued from the same triple cocoon. The results of these three rearings were as follows:

From two parent moths from a same double and grandparents from the same triple, two double cocoons and 68 singles were obtained.

From a second pair of parents, both from the same double, the grandparents each from a double, one double and 48 single cocoons were obtained.

From another pair of parents both from the same double and grandparents each from a double, 3 doubles and 73 singles were obtained.

In all the rearings (1904-5-6-7) the larvæ were *crowded* at spinning time if there were many larvæ in the lot.

The results seem to be plainly that (a) double cocooning is not

purely heritable and cannot be increased by selection or hybridization, and (b) that therefore it is an ontogenetic character but one not produced by crowding.

This conclusion seems quite opposed to that indicated by the statements of Duseigneur, Lambert and others. But nevertheless they are the only conclusions that can be derived from my data.

If the data did not include records of the second generation produced from matings made to test the possibility of the double cocooning habit as a Mendelian recessive, it might be assumed that this habit is of such a recessive character, not appearing in the first generation because of the dominance of the lack of the habit. But the data for the second generation although covering but few cases are unmistakable and definite so far as they go and show clearly that there is no basis for interpreting double cocooning behavior as a recessive character of alternative inheritance. The percentages of doubles appearing in the three second generation rearings are just about the percentages which might be expected to appear in any rearing, and are far too low to correspond to the expected percentage of a Mendelian recessive.

Although the single fact that in all the hundreds of rearings made in the laboratory in the last five years the spinning larvæ had been crowded in practically every case would indicate that the mere condition of crowding is not sufficient stimulus to determine double cocooning, it may be interesting to record the results of a few special experiments tried on individual worms to test the effect of crowding. Several times pairs of larvæ which had begun to spin double cocoons were separated and only very rarely in such cases was double cocooning given up. That is to say, such would-be double cocooners after being separated, in some cases 15 inches apart, would find their way together again and rebegin the double cocoon. In one case one of two larvæ which had begun a double cocoon together was removed and another larva ready to spin was substituted for it. The result was a desertion by both of the double cocoon already started and the spinning of a single cocoon by each. At another time 14 larvæ ready to spin were arranged in couples and each couple put into a space which compelled constant crowding of the two. Yet not one double cocoon was produced. All of the larvæ spun singles. Three larvæ ready to spin were introduced one into each of three nets already begun by three other larvæ. The result was six single cocoons, the introduced larvæ deserting the already begun net in each case.

Miss McCracken has paid some special attention to the question

of whether the double cocoon may not be the result of the labors of a single one of the two larvæ enclosed, the other being an individual which for some reason is not able to spin a cocoon, and hence attempts to become a room-mate with a normal spinning larva. She found in a number of cases that by separating two larvæ becoming enclosed in a common cocoon only one of the pair made a cocoon, the other spinning threads aimlessly or forming only a "carpet" and then pupating unprotected by a cocoon. In one or more cases the two larvæ becoming enclosed in a common cocoon showed by their attempts to spin single cocoons after being separated (one always succeeding) that they were spinners of differently colored silk. In no case however have we noted a double cocoon composed of two colors of threads. Miss McCracken's observations and suggestions should be followed up.

A little attention has been paid to note whether, in association of larvæ in spinning of double cocoons, sex cuts any figure. Double cocoons were often found to be produced by two females together or by a male and a female working together, but we have no recorded case of two males issuing from the same double cocoon. However, our records touching this point cover too short a series to be at all conclusive.

APPEARANCE AND BEHAVIOR OF "SPORTS."

In the seven years of our silkworm rearing there have appeared in various lots individuals showing sport characters of several kinds.

In 1903 various cocoonless pupæ were noted, the larvæ of these having spun no silk at all, or only a random "carpet," or they outlined cocoons only to neglect and leave them. Eight such cases were noted in 1903. Other larvæ spun only very thin, semi-transparent cocoons. In 1904 and 1905 other thin or skeleton cocooners were noted. Also larvæ that spun up after the third moulting (instead of the fourth as normally). Certain cocoons of extraordinary shape were also noted. Certain larvæ with caudal horn wholly wanting and others with this horn very short and small were observed. (Pl. I, fig. 12.) A few larvæ with curiously distorted body appeared (Pl. I, fig. 8). Also larvæ showing sport characters of coloration and pattern (Pl. I, fig. 9). The *moricaud* or all-dark color-pattern of the larva was found to be a frequent sport occurring in several races. (This has been the subject of breeding and inheritance testing by Coutagne, Toyama, Miss McCracken and myself and is referred to in the part of this paper devoted to a consideration of the alternative or Mendelian characteristics of the silkworm).

Moths appeared with sport wing patterns; also strongly melanic forms; also flying moths; also moths with rudimentary wings.

A great deal of work has been done in mating these sports and freaks, making rearings and following up the appearances for several generations, but for the most part only results of little value were got. In the matter of the *moricaud* or melanic larvæ more important data were obtained, especially by Miss McCracken. Some of the notes and results of the work with the other sports may be briefly referred to as follows:

Cocoonless and skeleton cocoon pupæ.—Rearings were made in 1905 from matings of sport individuals appearing in the general lots of 1904, and in 1906 from the 1905 moths produced from the 1904 matings. If there were no reappearance of the cocoonless character in the first hybrid generation (from a cocoonless and cocooning mating) it would not necessarily indicate the non-heritable character of the cocoonless habit but might show it to be a strictly recessive Mendelian character. The 1906 rearings from inbred hybrids should however reveal the recessive character again.

From seven rearings in 1905 from 1904 matings in each of which one or both parents were cocoonless, and seven rearings in 1906 from inbred matings from the 1905 generation the data show no transmission of the cocoonless character. It is ontogenetic.

Miscellaneous larval coloration sports.—From strongly pinkish, bluish and "black-face" larvæ descendants were obtained (the sports being crossbred with normal larvæ of their same race) without obtaining in either first or second generation (inbred hybrids) any reappearance of the sporting shades of color.

An interesting coloration sport which I have called "clouded head" (Pl. III, fig. 10) was noted in a lot of Bagdad race worms in 1906. Nearly one-half of a single lot of larvæ (a lot being the worms derived from all the eggs laid by a single female) showed in greater or less degree a "clouded head," a coloration of the dorsum of the thorax much like that of the familiar *moricaud* larval sport, but with the color pattern strictly limited to the dorsum of the thoracic segments. Four pure matings (i. e., "clouded head" with "clouded head") from this lot were made and the 1907 rearings from these were as follows:

(No. 230) More than 50 per cent. of the larvæ with clouded heads.

(No. 337) Eighty-nine clouded heads, forty-nine normals.

(No. 370) Twenty-two clouded heads, one hundred and fourteen normals.

(No. 415) One hundred and forty-four larvæ *all* with clouded heads.

Matings were made in 1907 from this material and will be reared this spring (1908).

Congenitally "hornless" larvæ.—Various matings were made in several years (inbred matings from first generation hybrids also mated for second generation rearings) of moths derived from larvæ born without the caudal horn or with it in greatly reduced condition (Pl. I, fig. 12). The results of all these matings show that the character is not heritable. That is, does not behave as a Mendelian or alternative character, nor can it be fostered and fixed by selection.

Experimentally "dehorned" larvæ.—The horn seems to be a useless structure. It is not an organ of defense, neither secreting an imitating or a mal-odorous fluid nor can it pierce or wound in any way an enemy. Besides, for nearly 5,000 years the silkworm has had no enemy except disease germs to defend itself against. This fact of the apparent present uselessness of the horn and the fact that it not infrequently appears in rudimentary condition or is even wholly wanting suggested the experimental mutilation of silkworm by removing this degenerating structure. Would such mutilations or removal of a structure already tending congenitally to degeneration or loss be more likely to be inherited as an "acquired character" than other mutilations such as have been brought about by experiment or custom and have shown no signs of being handed down to the young.

Considerable work was done during three successive years in testing this. In no case was there any indication of the transmission by inheritance of the mutilation. So this case may join the many others all of which (almost without question) have been repetitions of the same evidence of negation.

Sport wing pattern of moths.—In the seven years of rearings several well-marked sport variants of the wing pattern have appeared. Various matings to test the behavior in inheritance of these sports were made. For example, in 1905 two matings were made of a sport wing pattern with a normal wing pattern. In the first or hybrid generation there was no reappearance of the variant pattern. In rearings (1907) from inbreds from this hybrid (1906) generation there was also no reappearance of the sport pattern.

These pattern sports are various in character, some of them being asymmetries, some extreme emphasis of the normal faint patterning, some the appearance of large conspicuous well delimited black

blotches, etc. In no case has one of these sports yet shown any potency in heredity.

Melanic moths, not black, but with wings and body strongly smoky not infrequently appear (Pl. II, fig. 4). In various lots in various races these melanic or "darky" moths have been noted. And much work has been done in testing the inheritance behavior of this melanism. The general result is like that for all the other sporting characters (except the *moricaud* larval pattern) so far noted and studied, namely, it has no potency in heredity and does not behave as an alternative or Mendelian character. It shows a certain tendency in pure matings (that is smoky male mated with smoky female) to reproduce itself and careful selection could in time probably produce broods in which melanism would be the rule. The occurrence of melanic individuals is much more abundant among males than among females. No special evidence has yet been adduced to show that this melanism is not congenital, but is caused by special conditions surrounding the ontogeny. As all the individuals of any one lot of silkworms (by lot being meant all the worms derived from the eggs laid by a single female) are reared under as nearly identical conditions as possible, the occurrence of two or four or a dozen melanic moths in such a lot of two or three hundred individuals is evidence for the distinctly congenital nature of the variation. However, in some experiments which included the rearing of silkworms in an atmosphere of high humidity maintained during the whole larval life, the moths produced by these larvæ practically all showed a marked melanic tendency, although the character of the smoky coloration was somewhat different from that which often appears as a sport and which has given in my laboratory the name "darky" moths to the individuals showing the variation.

The studies into the nature and character of behavior in inheritance of this sporting melanism are being continued. (Eighteen matings were made on this basis in 1906 and most of the lots reared through to maturity in 1907, and a new set of matings made for the 1908 rearing season. The rearings made in earlier years from matings made on a basis of this character were unfortunately not well followed up).

Flying moths and moths with rudimentary wings.—The occasional appearance of male moths exhibiting a considerable power of flight (the silkworm moth although retaining its wings, probably in full size, has lost the power of flight, its wing-vibrations being no longer strong enough to carry its body), and the rarer appearance of moths with greatly reduced or rudimentary wings led to a number of matings to

test the inheritance possibilities of these variations. They were found to possess no special potency in transmission.

FERTILITY AS AFFECTED BY AGE OF THE GERM CELLS.

The theories of possible species differentiation on a basis of some sort of genetic or reproductive selection (Pearson) or reproductive divergence (Vernon) assume that without actual topographic isolation gradual differentiation within a species can come about through discriminate breeding or differences in fertility dependent on the association of sexual attraction or antipathy or actual degree of fertility with some other structural or physiological character in the individuals. It has been often suggested that such a relation may exist between age of the germ cells and degree of fertility. I have made a few observations in this connection.

When the silkworm moth issues from the cocoon it is sexually mature. Mating can take place and often does within a half hour after emergence and the results of this union are fertile eggs. The moths live usually for about three or four days after emergence, at the most but six or seven, so that the age of the moth, and accordingly of the germ cells in functionally active condition, should be reckoned by hours. Matings between moths of exactly known but differing ages were made. For example, males not over four hours old were mated with females as old as fifty-two hours, and with others not over four hours old. Males fifty-six hours old were mated with females just issued and with other females much older. And so on. The eggs from the matings were counted and after the development of the eggs had proceeded for some months the eggs were again counted to the end of determining how many were developing and how many were not.

The results of the experiments show that eggs from parents in which the male is old did not develop as well as eggs from other parents. That is, the extreme age of the female (egg cells) seems to make no difference in regard to the developing power of the fertilized eggs. But the age of the male (sperm cells) does seem to affect the fertility of the eggs. Very old males (sperm cells) seem to be less potent than younger ones.

ECONOMIC ASPECTS OF STUDIES IN SILK-WORM INHERITANCE.

In their recent comprehensive treatise (*Traité sur le Ver a Soie du Murier et sur le Murier*, 1906) on commercial silkworm rearing, Maillot and Lambert of the principal government experimental silk culture station of France (at Montpellier) discuss the effects and advantages of the crossing of silkworm races and of individuals of the same race reared in separated localities. Their statements are based on the experience of long years of rearing, observation and selection.

First, they find that crossing, even between moths of closely allied races, produces individuals "more vigorous, more productive, more fecund."

Then they utter certain generalizations concerning the results to be expected from certain crossings. For example: "if one mate a male moth of a race that lays adherent eggs with a female moth of a race laying non-adherent eggs there will be more chances that the eggs produced by the hybrid young will be non-adherent; but in the reciprocal crossing [i. e. male of non-adherent eggs with female with adherent] the contrary will most often occur."

Also "if one crosses a race with large, cylindrical, yellow cocoons and worms large and of slow growth, with a race with small, oval, white cocoons and worms smaller and of rapid development, one will have in the first generation both yellow and white cocoons, of each type, sometimes in numbers almost equal, sometimes many more of one type than of the other; the worms will differ from worm to worm: some will be of the type of the male race, large and long lived; others will be of the type of the female race, small and short lived; others yet will show the characters of both races. Thus in a crossing of worms with white skin with worms of black skin one will find sometimes individuals which have half of the body with the skin black the other half with the skin white. The separating line being the median longitudinal one.

"In the crossings between races of differently colored cocoons the most advantageous one, that which offers the best guarantee in the matter of the homogenousness of the cocoons produced, both as to quality and quantity, will be a crossing of a male of yellow cocoon with a female of white cocoon. One can affirm nothing with certainty concerning the inheritance of the tendency which is shown

by the worms of certain races, as the races of Japan and several of China, to combine two or more in the same cocoon, that is to make what are called double cocoons; it seems, however, that in this respect the hybrids tend more often to follow the female than the male.

"Finally if one mates hybrids among themselves one will find in the worms and cocoons a diversity of size, form and color much greater than would be found in the direct descendants of the parents and this great diversity in the cocoons depreciates them much in the eyes of the spinners.

"The principal advantages of these crossings is the production of worms very vigorous and very robust which resist the disease of flaccidity better than do the native races of yellow or white cocoons and which give at the same time a tolerable harvest in places in which the European races produce rarely a harvest worth gathering; besides they are very much more precocious and form their cocoons sooner.

"But aside from these advantages these crossings are disadvantageous by producing worms and cocoons very often dissimilar, sometimes following more one race, sometimes more the other, and if one intermates the hybrids one obtains products of a still greater diversity. It is wise therefore to confine oneself to rearing worms issuing directly from an original crossing and of repeating this crossing each year. But for this it is necessary of course to make rearings each year of the two pure races of which one proposes to make the crossings. This is, of course, a disadvantage and a complication."

These are practically all of the generalizations touching the "effects of crossing" which the authors of this modern authoritative treatise on silkworm culture permit themselves to express. Without doubt they might, from the large experience and the long series of rearings carried on by their station, utter many more. But, and this is the point to which I wish to call attention, of how curiously indefinite and unsatisfactory character are such generalizations compared with those which can be expressed after even so few years of experimental breeding as those of Toyama and myself in the light of the modern scientific study of heredity.

The knowledge of the definite Mendelian character of the inheritance of certain characteristics and the knowledge that certain other characteristics are not inherited according to Mendelian principles but must be fostered and maintained by strict personal selection, can be a potent help to the commercial silk grower in his attempts to produce new races especially fit for his particular need and use.

Whereas without a knowledge of the Mendelian behavior of certain characteristics it might take many generations of rearing the products of various crossings and selections—Maillot and Lambert record that it required 70 generations to establish a certain particular race—with this tested knowledge of the behavior in inheritance of specific characters it would be quite possible to fix certain characters in from three to five or six generations.

Experimental breeding with Mendelian principles in mind will enable the professional silk grower to determine speedily the simple or compound nature of the characteristics of the eggs, larvæ, and cocoons; will enable him to analyze the compound characters into their component simple ones; will permit him to establish combinations, even very elaborate ones, comparatively rapidly (at least of such characteristics, as show alternative inheritance, that is are Mendelian in behavior), and will save him much waste of time in purely empirical work.

His first aim in crossing and selecting will not be the establishment of the desired combination by long-continued miscellaneous trials, but will be the determination of the actual status, as regards behavior in inheritance, of the characteristics he desires to combine and fix. He will determine for each of these characteristics (and two or three generations will tell him) their inheritance habit. Are they unit characters? Are they strictly alternative in inheritance? Or do they combine in the hybrids in particulate (mosaic) manner, or as true blends? Or finally are they so strictly of the nature of simple fluctuations of varying degree or extent about a modal characteristic that they tend strongly to drop back towards this modal type or condition so that only the strictest and most continuous sort of personal selection can maintain them?

Among the characters and conditions of eggs, larvæ and cocoons forming, in various combinations and degrees of emphasis, the diagnostic marks of the present silkworm races, characteristics showing all these types or modes of inheritance are included. Color of silk, an important character, behaves usually as a unit character, alternative in inheritance, following, in some degree, the Mendelian principles. Certain colors are then recessive towards others, as white to yellow; salmon to yellow, etc. The relative status of potency (dominancy or recessiveness) can be definitely determined for any two colors, and the silk breeder thus have a knowledge of enormous usefulness in his work of crossing and selecting. Richness in silk (i. e. proportion of

quantity of silk to total weight of cocoon and enclosed pupa) is purely a fluctuating characteristic, capable of a certain amount of amelioration by persistent, rigid, personal selection. Double cocooning is a characteristic, from the evidence of my data, not heritable but ontogenetic, although from the statements of Duseigneur and Lambert it would seem to be heritable; it is a characteristic needing more study to determine its actual behavior or status in inheritance.

But it is, as said in the introductory paragraphs of this paper, not my intention to consider at present in any detail the economic aspects of our present knowledge of the status in inheritance of the characters. I hope to be able in a future paper to offer some discussion of this subject.

GENERAL DISCUSSION.

I shall undertake no real general discussion of the problems of inheritance: not even of those particular ones upon which this silkworm work may have some bearing. The few points to which I shall here briefly call the reader's attention will be chiefly simply by way of indicating or drawing certain comparisons with the conclusions of Toyama (Bull. Coll. Agric., Tokyo Imp. Univ. v. 7, pp. 259-391, 1906) based on his similar work with silkworms, and with those of Davenport (Paper No. 7 of the Carnegie Station for Experimental Evolution, 1906) based on his work with poultry.

Toyama finds the larval variations of color-pattern and the cocoon differences of color to follow Mendel's law, and to behave with equal consistency and regularity. I do not. By the use of many repetition or check lots I find the larval characters to exhibit a great fidelity to Mendelian principles in their mode of inheritance, but with the cocoon colors I find exceptions so numerous, so various, and so pronounced as to lead me to lay great stress on the potency or influence of individual and strain idiosyncrasies. My position in this matter has been already definitely set out in this paper in the sub-section "*Conclusions*" of the section "Strain and Individual Idiosyncrasies" (p. 33).

I have stated there what seems to me to be the probable significance of the facts of this marked difference in the consistency of the inheritance behavior of these two sets of characters. This significance is, in a word, that the regularity and consistency of the behavior of the larval characters result from their natural origin and fixation as contrasted with the more artificial or man-controlled origin and fixation of the cocoon characters, and that the evidence suggests the mutational origin of the stable larval differences as contrasted with the origin of the cocoon characters through the selection of fluctuating variations.

However, this significance may not come to my readers with any of the force with which it comes to me. If not I still wish to direct their attention to the definite character, at least, of the differences in consistency and regularity of the inheritance behavior of the two sets of characteristics, and the inevitable conclusion that the heredity of the silkworm is not to be expressed by any single fascinating sweeping generalization as to its regularity. The longer the series of check lots, the greater the opportunity the silkworm is given to reveal inconsistencies in its heredity (that is, inconsistencies from our favorite point

of view today, i. e. the Mendelian point of view), the more numerous and various and pronounced and confusing (or illuminating if we are simply searching for truth and not the truth of a single hypothesis) these inconsistencies become.

On the other hand it is also a point not to be overlooked that these inconsistencies are only put into the conspicuous position they occupy by the strong and suggestive tendency through all the silkworm heredity towards Mendelian behavior. And it may very well be that some more thorough-going student and more subtle interpreter than I of inheritance phenomena will be able to analyze many of the phenomena which seem to me to be inconsistencies and exceptions to the Mendelian principles in such a way as to reveal the possibility if not actuality of their basic consistency with these principles. Professor Bateson has exhibited so much ingenuity in analysis of the various apparently unconformable cases of inheritance presented to him that a student less well grounded and less gifted can not venture to be too certain in the interpretation of his data. By the addition of the hypothesis of determiners and cryptomeres to a keen analysis of the data offered him, Bateson has most plausibly brought into line with Mendelism numerous at first sight non-Mendelian cases. Very well. He has now on hand for treatment apparently unconformable new data and interpretations from both Davenport and myself.

This reference to Davenport's results and conclusions leads me directly to say that on the whole my results with the silkworm and my interpretations of and conclusions from these results are very much like those of his, derived from his extended work with poultry. With Davenport, I find dominance and recessiveness often incomplete; prepotency as truly important as dominance; the theory of gametic purity not borne out with any rigorousness by the data of crossings. Differing from him, I find reciprocal crosses (on basis of sex) not exhibiting important or consistent differences in inheritance; where such differences in reciprocal cross results occur they can more readily be ranked in the category of "individual idiosyncrasies" than in the category of sex influence. I find no special evidence to favor Conklin and Guyer's contention for a larger influence in inheritance on the part of the female because of the larger mass of cytoplasm in the female germ cells. Indeed Miss McCracken finds in her intensive study of the inheritance in silkworms of larval melanism and imaginal polyvoltinism that if either sex shows any prepotency it is the male sex.

I find much more inheritance difference on a basis of strain or race

differences than Davenport seems to, although he finds some. These are my differences due to "strain idiosyncrasies."

The significance of my data as regards the pressing question of the chief influences in species change seems to me to be that of pointing toward the sudden appearance of definite discontinuous fixed differences either of the nature of new unit characters or of new combinations of old unit characters, endowed from the start with taxonomic stability, behaving in heredity as consistent alternative characteristics along Mendelian lines. In other words it seems to me that my data indicate the reality of mutations as real species differentiating characters. The visible differences between hereditary strains of organisms based on the accumulation of fluctuating variations by some method of selection may be even larger in appearance than the mutational differences and yet lack the stability and hence fundamental reality of these latter differences. Apparently, however, by some means they may come to acquire the inheritance behavior and stability of the mutational differences. At least the cocoon differences in silk worms which are the result of selection methods seem to be tending strongly toward the acquirement of the same type of inheritance, viz., alternative Mendelian inheritance, as that of the larval characteristics. If this condition can be really attained then the differences will be as real and species-distinguishing as those which arise as mutations.

But I concede readily that my conclusions are not so inevitable from my data as my expression of them would seem to indicate. And I wish to leave with my readers no wrong impression of an overestimate on my part either of the value of the data themselves or of the worth of the few generalizing conclusions expressed in this paper. I offer the data as facts as nearly as I can see and describe them, contributing toward our gradually growing knowledge of inheritance phenomena.

SUMMARY OF RESULTS AND CONCLUSIONS.

Silkworms exhibit some characteristics which are alternative in inheritance and which follow in their transmission exactly or with more or less approximation Mendelian proportions. But some of these characteristics are not very stable in their alternative and Mendelian behavior. Other characteristics still are not discontinuous or alternative in character or inheritance but are of the nature of fluctuating variations and are strongly obedient to Galton's law of regression.

Larval color-pattern differences are consistently and rigorously alternative and Mendelian in inheritance; cocoon colors tend to be alternative and Mendelian in behavior but are inconsistent as to dominance and recessiveness and numerical proportions, and may even break down and blend, or one color be otherwise influenced or modified by the presence, in a mating, of another.

Larval pattern and cocoon color characters do not except as coincidences follow the same parent in dominance. In cross matings combining opposed larval and cocoon characters dominance in larval pattern may be with the paternal type, in the cocoon color with the maternal, or *vice versa*, or both dominances may rest with the paternal or with the maternal type. Dominance is a function of the characteristic not of the parental influence. Dominance is also not a function of sex or of bodily vigor.

While in larval color-pattern characters the inheritance behavior is rigorously alternative and Mendelian, dominance always being consistent in relation to a given color-pattern as related to another, this is not true of cocoon colors. With these characteristics differences peculiar to strain (or race) and individual are marked. Strain and individual idiosyncrasies are real and important and thus sweeping generalizations concerning the inheritance behavior of the cocoon colors tending to class them unqualifiedly in the Mendelian category cannot be made. The tendency is for them to behave in Mendelian manner, but it is a tendency subject to numerous, marked and various inconsistencies and irregularities.

In double matings, i. e. mating of one female with more than one male, these males representing different types of larval and cocoon characters, interesting modifications and interactions of influence are to be noted. The reality of strain potency over character potency is made manifest in these double matings.

Quantity and quality of silk, subsidiary larval markings, wing-pattern and wing-venation variations, and degree of adhesiveness of eggs are all fluctuating, non-alternative characters.

Double cocooning is a phenomenon determined by ontogenetic circumstances. Crowding is not the causal circumstance.

Of various sport appearances of larval, cocoon, and imaginal characters only one, namely, larval melanism or moricaudness, is of pre-potent or dominant nature when crossed with the normal condition. All other sport characteristics including various larval color and structural abnormalities, active flight of moths, absence or rudimentary condition of wings, unusual color patterns, including melanism, of moths, are extinguished in cross-matings.

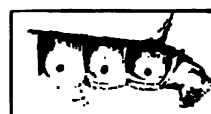
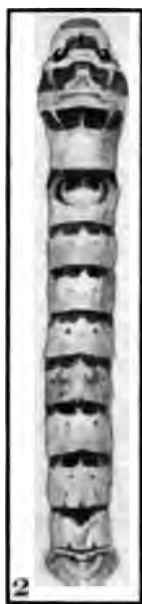
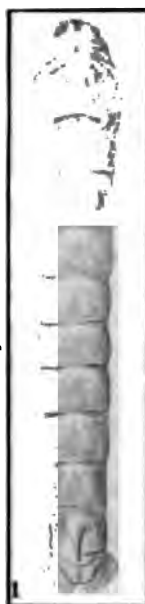
Fertility is not affected by the age of the egg cells but seems to be unfavorably affected by the age of the spermatozoa. Old spermatozoa seem less potent than younger ones.

A scientific study of inheritance in silkworms can be of service to commercial silk culture.

PLATE I.

(LARVÆ, NAT. SIZE.)

- Fig. 1. Italian Salmon race, white type, in last instar.
- Fig. 2. Italian Salmon race, tiger-banded or zebra type, in last instar.
- Fig. 3. Galbin Italiano race, in 4th instar.
- Fig. 4. Japanese White race, in 4th instar.
- Fig. 5. Mosaic of tiger-banded and pattern types, last instar.
- Fig. 6. Clayey-yellow or "muddy" type, last instar.
- Fig. 7. Chinese White race, in 4th instar.
- Fig. 8. Sport or abnormality, in 4th instar.
- Fig. 9. Sport pattern, spot marking on segments, in 4th instar.
- Fig. 10. Japanese White race, in 3rd instar.
- Fig. 11. Front view of head and thoracic segments, showing variations in thoracic markings ("eyebrows").
- Fig. 12. Posterior segments of three specimens, showing "hornless," "tubercled" and "fully horned" conditions.



fly (*Melitæa sp.*), and mourning-cloak butterfly (*Euvanesa antiopa*) also steadily lose weight from day to day, this loss being very considerable in two of these species, viz., about 35 per cent. in the case of one and 65 per cent. in the case of the other.

(with R. G. Bell) Variations Induced in Larval, Pupal and Imaginal Stages of *Bombyx mori* by Controlled Varying Food Supply, in *Science* N. S. v. 18, pp 741-748, December, 1904.

One of the races of the mulberry silkworm was made the subject of experiments directed toward a determination of the exact quantitative relation which quantity and quality of food bear to the development and variations of the individual insect, and to the maintenance or transmission of these variations to its progeny.

The change in quality of food consisted of a substitution of lettuce for mulberry. The lettuce-fed worms went through their moults, spinning up, pupation and issuance as adults successfully. They mated freely and laid eggs which developed normally. The young larvæ adopted the unusual diet very reluctantly, but in later life these same larvæ, "educated" to its use, ate lettuce with a relish which rivaled that displayed by the normal larva with its mulberry leaf.

The most striking variation induced by this lettuce regimen was that the time consumed by the metamorphosis was double the time appointed for that of the normal mulberry-fed larva—being three months as compared with six weeks for the latter. In the commercial world this fact would offset the advantage of the lettuce, as a cheaper food and as one available at all seasons, by demanding twice the labor that is required to rear to spinning time larvæ fed on mulberry. Thus it appears that the lettuce experiment can not be of economic value to sericulture unless it should prove that lettuce-made silk is worth the cost of double labor.

The other variations noted among the lettuce-fed "worms" have to do with the larva and cocoon. All of the lettuce-fed larvæ appeared to be unusually "thin skinned," the body wall being stretched and shiny. The larvæ were at all stages characteristically heavier than mulberry-fed larvæ, each of them weighing at spinning time as much as, and two of them weighing 400 mg. more than the heaviest of the mulberry-fed. The weights of the cocooned pupæ were somewhat above the average among the mulberry-fed, a fact due to the large pupa rather than to the amount of silk in the cocoon, as was demonstrated by weighing cocoon and pupa separately, whereupon it was found that the cocoon was, on the average, but one-half as heavy as that of the average among the mulberry-fed, in some cases falling as low as two-fifths of the mulberry cocoon's average weight, and in no case rising above three-fifths. The silk appears to be less strong and elastic than that of the mulberry-made cocoon.

In the mulberry-fed worms there exists a very definite and constant relation between amount of food and size as indicated by weight, the starveling individuals being consistently smaller than the well nourished, the lingering effects of this dwarfing being handed down even unto the third generation, although the progeny of the famine generation be fed the optimum amount of food; in case the diminished nourishment is imposed upon three or even two successive generations there is produced a diminutive, but still fertile, race of Lilliputian

silkworms whose moths, as regards wing expanse, might join the ranks of the micro-Lepidoptera almost unremarked.

In illustration may be quoted the typical or modal larval weights for each of the lots of 1903 at the time of readiness to spin, which marks the completion of the feeding and is, therefore, an advantageous point for a summary of the results of the three years' experimental feeding.

The history of the eight lots referred to may be gathered from an examination of the accompanying table, in which "O" means optimum amount of food and "S" means short rations. The column to the right indicates the relative rank of the various lots as judged by the modes of frequency polygons erected to include all the individual weights for each lot at spinning time.

Lot Number	HISTORY OF LOTS			Modal Rank 1903
	1901 Grandparents	1902 Parents	1903	
1	O	O	O	1
2	O	O	S	6
3	O	S	O	3
4	O	S	S	7
5	S	O	S	2
6	S	O	S	5
7	S	S	O	4
8	S	S	S	8

We find that control lot 1, consisting of normally fed individuals of normal ancestry, holds first rank in weight, as was to be expected. Second comes lot 5, whose grandparents experienced a famine but whose parents as well as themselves enjoyed years of plenty. Lots 2 and 3 have likewise had one ancestral generation on short rations, and the fact that they are lighter in weight than lot 5 illustrates a general rule which obtains throughout the entire company of experimental worms, namely, that the effects of famine grow less evident the further removed the individuals are from its occurrence in their ancestral history. Thus lot 5 is two generations removed from the famine of 1901, while lot 3 has had but one generation in which to recover its ancestral loss. Lot 2, which has had a total of but one famine year—the current year—nevertheless ranks below lot 7, which has had two famine years in its ancestry succeeded by plenty during the current year. Lot 2 also ranks below lot 6, a fact which appears strange, considering that lot 6 has suffered two generations of famine, including the current year, which is the only famine year experienced by lot 2. In explanation of this anomalous condition it is suggested that possibly the larvæ of lot 6 were better fitted for enduring the making the best of hard conditions than were the individuals of lot 2, the ancestors of the former lot having been selected two years ago on a food-scarcity basis. This suggestion gathers support from an inspection of the mortality notes, from which it appears that the number of

deaths—for which the famine was probably a contributing and not a primary cause—in each lot which is for the first time subjected to short rations is almost doubly greater than the number of deaths in lots which are descended from starved ancestors, whether these ancestral famines occurred in successive or alternate years. The figures indicate that a reduction of food is almost twice as destructive upon the first generation which is subjected to it as it is when visited on a second generation. Lot 4 follows lot 2 as the seventh in rank and its position is in accord with the rule above noted, its latest ancestral generation which enjoyed an optimum amount of food having been grand-parental, whereas the ancestors of all the other lots except lot 8 have had the optimum amount of food during 1902 or 1903. Lot 8 holds lowest rank, it and its ancestors having been subject to trying conditions throughout the entire three years, during some one or two of which all the other lots have enjoyed the best of food conditions. Thus it appears that a generation of famine leaves its impression upon at least the three generations which succeed it, yet the power of recovery through generous feeding exhibited by the progeny of individuals subjected to famine is so extensive (witness lot 5) that it appears probable that every trace left by the famine upon the race would eventually disappear. It is even conceivable that the ultimate result of the famine would be a strengthening of the race, the famine having acted the part of a selective agent, preserving only the strong.

That conditions of alimentation bear a directive relation to functional activity may be demonstrated by reference to the records of the physiological functions of moulting, spinning, pupating and emerging, of the individuals of the experimental lots.

An abnormal extension of the time needed for the metamorphosis follows upon a reduction of the food supply. The degree of extension depends with the utmost nicety upon the amount of food given the larvæ. For example, among the 1901 generation of silkworms, one control lot of twenty larvæ was given the optimum amount of food, a second lot of twenty larvæ one-half this amount, and a third lot of twenty larvæ one-quarter of the amount. To take the time of the fourth moulting as an illustration, the moulting was begun by the first lot, which led the way by two and a half days, at the end of which the second lot began to moult, while the third lot was twenty-four hours behind the second. All the individuals of the first lot had finished moulting on April 20, all of the second on April 24, while the moulting in the third lot continued until April 29.

As in the matter of weight, this retarding of the functions, by means of a reduced food supply, affects not only the immediate generation which is subjected to the famine, but the lingering effects of it may be traced in the progeny of the dwarfed individuals at least unto the third generation, even though two years of plenty follow the one year of famine. The conditions which obtain in each lot of individuals of the 1903 generation at spinning time are shown in the following table, which is based upon polygons erected to include all the individuals in each lot.

LOT NUMBER	HISTORY OF LOTS			RANK OF 1903 LOTS AS TO PROMPTNESS IN SPINNING			
	1901 Grandparents	1902 Parents	1903	Earliest Spinner	When Two-Thirds of Each Lot Were Spinning		Latest Spinner
					Date	In Order of Rank	
1	O	O	O	1	May 12	1	1
2	O	O	S	5	" 25	4	4
3	O	S	O	2	" 13	2	3
4	O	S	S	4	" 26	5	5
5	S	O	O	3	" 13	2	2
6	S	O	S	6	" 29	6	7
7	S	S	O	6	" 22	3	5
8	S	S	S	7	" 30	7	6

This period in the silkworm's life is particularly advantageous for consideration here because it marks the completion of the feeding, so that the individuals of under-fed ancestry have been given the best chance to recover, while those subject to altered food conditions have had the benefit of the alteration during the entire food-taking period of life.

In the table "O" means optimum amount of food and "S" means short rations. To the right of the history of the lots is a section showing the rank of the lots as to the extreme time limits of the spinning time (emphasized congenital differences again), with a safer criterion, as to their relative promptness, in the column between the extremes—a column of figures intended to show the relative promptness with which a two-thirds majority of the larvæ in each lot arrives at the spinning time, this proportion being taken to represent the typical condition for the lot. The order in which the lots are arranged in this column corresponds in a general way with that prevalent for the weights at spinning time, and the generalizations indulged in there may with few exceptions be applied here. The lots which were well fed during the 1903 generation are ahead of all of those given short rations in 1903, whatever ancestry they may have had. Lot 1 leads here as in the matter of weight. Lots 3 and 5 tie for second place, having held second and third places in weight. Lots 2 and 4 stand in the same relation to one another that they held as to weight. Contrary to the weight relation, lot 6 follows lot 2 at the spinning—a fact which illustrates again the general rule that two generations of famine are more disastrous than one, but does not lend support to the notion of natural selection on a food scarcity basis as previously suggested. Lot 8, which has had no relief from famine during the entire three years, brings up the rear at the spinning, as might be expected.

As to the life and death selection due to famine, it may be said, in addition to the previous discussion of mortality among the experimental silkworms, that while lots subjected to two years of famine (themselves in one year, their parents in the year before) were fertile in so far as number of young hatched is concerned, it was found to be exceedingly difficult to rear from them a 1903 generation. Indeed, at the time of the second moulting there were but nineteen

individuals (and tolerably vigorous larvæ they were) alive in the lot which had experienced two years of famine, although every individual of the 149 hatched was carefully preserved and royally fed—a fact which goes to prove that the equipment at birth of many of these larvæ was inadequate.

The fact that some larvæ of starved ancestry have exhibited a superiority over their fellows, in surviving and recovering from hard conditions, is testimony for the existence of individual variations which can not be defined anatomically, and yet which serve as “handles” for natural selective agents. Such variations might be called physiological variations, since it seems that the surviving larvæ must be those which are in best trim physiologically. These larvæ are able to make the most of the food offered to them. If competition were allowed, they would probably be the individuals which would cover the area most rapidly, securing whatever food there might be. But under our experimental conditions there was no competition allowed and yet certain precocious individuals made more grams of flesh and more yards of silk, than other larvæ furnished with the same amount of raw material under like conditions; that this was due to the possession by the former of certain congenital qualities of adaptability can scarcely be doubted.

As to the fertility of the variously fed lots; in so far as number of eggs produced is a measure of fertility, our records already demonstrate the fact that the better nourished are the more fertile. Furthermore, the economy in this matter practised by the starvelings is not merely numerical, quality as well as quantity of eggs being affected. In witness of this point may be recalled the story of the dying 1903 generation, produced from eggs of the starvelings of 1901 and 1902, which would seem to offer conclusive evidence that a famine suffered by the parents works its way into the germ cells so that most of their progeny have but a poor birthright.

Regeneration in Larval Legs of Silkworms, in Jour. Exper. Zool., v. 1, pp 593-599, 10 figs., Dec., 1904.

Experimenters in regeneration in insects have too often overlooked the fact that the imaginal (adult) legs of insects of complete metamorphosis are produced not by a direct transformation of the corresponding larval thoracic legs but from new centers called imaginal discs or histoblasts. These histoblasts are developed from an invagination of the larval cellular skin layer (hypoderm) and only in comparatively late larval life do the new developing imaginal legs lie within the larval ones. It follows from this that if a larval leg be cut off in early larval life the imaginal leg is in no way mutilated, and that if it appears of full size and normal character in the adult insect, this is not due to restorative regeneration but simply to its normal growth and development. If a leg be cut off in late larval life, the developing imaginal leg may or may not be at the same time mutilated. If mutilated, however, it will always be by a removal of much less of its extent than of the extent of the larval leg taken off. A cut which severs the larval leg near its base (for example, through the base of the femur), will not take off more than the tarsus or perhaps part of the tibia and tarsus of the imaginal leg, which, in its development, is beginning to extend into the larval one. Thus if the imaginal leg be found, when the imago issues, to lack a tarsus

but to possess a complete femur and tibia, this is no indication that there has been a partial regeneration; there may have been none whatever.

To make a definite test of the capacity of the silkworm to regenerate lost parts, legs, both thoracic and abdominal, were cut off of the larva at various ages and at various places between the tarsus and the body, and notice was taken of whether or not regeneration of these legs took place before pupation, and if so in what degree, and whether normally, *i. e.*, so as to produce an exact replica of the lost leg, or not.

The results of the experiments show, (a) that the larva of the silkworm moth, *Bombyx mori*, has the capacity of regenerating its thoracic and abdominal (prop-) legs from the stumps of these legs, but not from the body (trunk), *i. e.*, that each leg has the capacity to regenerate any distal part from any proximal part, but that the body can not produce a wholly new leg; (b) that this regeneration shows externally not after the first moulting after the mutilation but after the second moulting, and that the regenerative processes are completed with the appearance of the new parts after this second moulting succeeding the mutilation.

The small caudal horn, a pointed non-segmented, but movable, process projecting upward from the dorsal surface of the penultimate abdominal segment was cut off in many larvæ (silkworms) of various ages, and in no case was there the slightest regeneration. After the first moulting succeeding the mutilation the new skin always extended smoothly over the place where the horn had been, without any sign of scar.

The function of this horn, which occurs on some other lepidopterous larvæ, notable and characteristically on the larvæ of the Sphingid moths, is unknown. It has been explained by some entomologists as an ornament, by others as a "terrifying organ." It is not a sting nor in any way an effective weapon of defense, as even where long and conspicuous ($\frac{1}{3}$ in. long) it is weak and easily bent. Nor does it secrete an acrid or ill-smelling fluid. Certainly in the silkworm it has had for many hundreds of generations no possible function as a weapon. It is interesting to note that this useless organ is not regenerated.

Relation of Regeneration to Natural Selection.—This suggests to us a consideration of the relation of regeneration, as we have observed it in the silkworm, to its causes, or at least to natural selection as an explaining cause. If the caudal horn is now a useless organ in the silkworm body its lack of capacity to regenerate (loss of capacity, if it ever had it) would seem to favor the theory of the natural selectionists concerning regeneration. At first glance, also, the retaining of the regenerative capacity of the legs, useful organs, may seem to favor this theory. But it must be borne in mind that the silkworm has been for approximately 5000 years a domesticated animal cared for under such conditions as to make the natural loss of legs almost an impossible occurrence.

Perfectly protected against such natural enemies as bite off legs, there has certainly been nothing of that sharp necessity, during all the life of countless successive generations of silkworms, which is supposed to be the basis for maintaining the advantageous capacity for regeneration. There has been a clear field for panmixia. But the regenerative capacity still exists in effective degree. The silkworm offers little aid and comfort to those who would explain regeneration wholly as a phenomenon fostered and maintained by natural selection on a basis of utility.

Influence of the Primary Reproductive Organs on the Secondary Sexual Characters, in Jour. Exper. Zool., v. 1, pp 601-605, Dec., 1904.

In this paper is recorded an account of the process of extirpating the developing ovaries and testes of various silkworm individuals in various larval stages. These individuals after pupation and issuance as adults were then examined to note if any change or lack of normal development had taken place in those structures showing secondary sexual differences, particularly the antennæ.

The extirpation of the developing reproductive organs, which lie just beneath the dorsal wall in the fifth abdominal segment, was accomplished by searing with a hot needle. The slight wounds soon closed, and most of the larvæ were reared to moths. In all cases the moths were dissected to be sure that the destroying of the ovaries or testes had been complete and to see whether any regeneration of these parts had taken place. No such regeneration occurred, and in a score of moths the ovary or testis of one or both sides was found to be wholly wanting.

There was no case of the absence or modification of the secondary sexual characters in any of the moths. All males had both antennæ of the usual male type, although the testis of one side or the other, or of both sides, was wholly wanting.

Some Silkworm Moth Reflexes, in Biol. Bull., v. 12, pp 152-154, Feb., 1907.

Silkworm moths, *Bombyx mori*, are sexually mature and eager to mate immediately on issuing from the pupal cocoon. They take no food (their mouth parts are atrophied), they do not fly, they are unresponsive to light; their whole behavior, in fact, is determined by their response to the mating and egg-laying instincts. We have thus an animal of considerable complexity of organization, belonging to a group of organisms well advanced in the animal scale, in a most simple state for experimentation.

The female moth, nearly immobile, protrudes a paired scent-organ from the hindmost abdominal segment, and the male, walking nervously about and fluttering its useless wings, soon finds the female by virtue of its chemotactic response to the emanating odor. Males find the females exclusively by this response, but orient themselves for copulation (after reaching the female) by contact. When two males accidentally come into contact in their moving about they try persistently to copulate.

A male with antennæ intact, but with eyes blackened, finds females immediately and with just as much precision as those with eyes unblackened. A male with antennæ off and eyes unblackened does not find females unless by accident in its aimless moving about. But if a male with antennæ off does come into contact, by chance, with a female it always (or nearly so) readily and immediately mates. The male is not excited before touching the female, but is immediately and strongly so after coming in contact with her. Males with antennæ on become strongly excited when a female is brought within several inches of them.

The protruded scent-glands of the female are withdrawn into the body immediately on her being touched by a male. If the scent-glands are cut off and put wholly apart from the female, males are as strongly attracted to these

isolated scent-glands as they are to unmutated females; on the contrary they are not at all attracted to the mutilated females. If the cut-out scent-glands are put by the side of and but a little apart from the female from which they are taken, the males always neglect the near-by live female and go directly to the scent-glands. Males attracted to the isolated scent-glands remain by them persistently trying to copulate with them, moving excitedly around and around them and over and over them with the external genitalia vainly trying to seize them.

The behavior of males with the antenna of only one side removed is striking. A male with left antenna off when within three or four inches of a female (with protruded scent-glands) becomes strongly excited and moves energetically around in repeated circles to the right, or rather in a flat spiral thus getting (usually) gradually nearer and nearer the female and finally coming into contact with her, when he is immediately controlled by the contact stimulus. A male with right antenna off circles or spirals to the left. It is a curious sight to see two males with right and left antenna off, respectively, circling violently about in opposite directions when he immobile female a few inches removed protrudes her scent-glands. This behavior is quite in accordance with Loeb's explanation of the forward movement of bilaterally symmetrical animals.

The results of all the experiments tried show how rigorously the male moths are controlled by the scent attraction (chemotropism) and how absolutely dependent mating (the one adult performance of the males) is on this reaction. If we can find specialized animals in a condition where all attractions and repulsions (stimuli) but one are eliminated we may readily perceive the rigorous control exercised by this remaining one. We are, unfortunately, in the general circumstances of animal life too much limited to the use of very simply organized animals for reaction and reflex experimentation. This tends to make it difficult to carry over to the behavior of complexly organized animals the physico-chemical interpretation which is steadily gaining ground as the key to the understanding of the springs and character of the behavior of the simplest organisms. But where the complex stimuli and reactions that determine the behavior of complexly organized forms can be isolated and studied the inevitableness of much of this behavior can be recognized.

Reflexes of Moths Without Cephalic and Thoracic Ganglia.—A number of experiments was made to determine the need, or absence of need, of the principal ganglia of the central nervous system in the performance of the two chief reflexes in the silkworm moth's life, *viz.*, mating and egg-laying.

Males mate with headless females, and the headless females, after mating, lay a few eggs which develop normally, that is become fertilized by the release of spermatozoa from the spermatheca in the female's body, are oviposited by the repeated extrusion and retraction of the ovipositor, and make the usual color changes (from yellow to cherry-red and then to lead-gray) incidental to normal development. But in no case did a headless female lay her full complement of eggs, in fact in no case were more than a score of eggs laid (the normal number is from 200 to 350). Headless females (and headless males) usually live as long as unmutated individuals, *i. e.*, from a week to two weeks.

Females with head and thorax cut off (and even part of the abdomen) can be mated with by males, and this fractional part of the female can fertilize

and oviposit a few eggs which begin normal development. In one case 10 eggs, of which 8 are now normally developing were oviposited by such an impregnated part of female abdomen, this abdominal relict remaining alive (!), i. e., flexible and responsive to stimulus and capable of extruding the ovipositor and laying eggs, for forty hours.

Males with head removed can not find females, nor can they mate if placed in contact with them. When the head or head and prothorax of a male is cut off immediately after the male and female are *in copulo* the female, although uninjured, lays no eggs. If heads of both males and females *in copulo* are removed no eggs are laid although both moths remain alive usually as long as do unmutated individuals.

A silkworm moth can maintain itself right side up with antennæ off or with antennæ off and eyes blackened, but with head off one position seems indistinguishable from another to it, i. e., it lies on one side or the other, on the venter or dorsum equally willingly. The organs of equilibrium are not on the antennæ, then, but are lost when the rest of the head is removed.

Sex Differentiation in Larval Insects, in Biol. Bull., v. 12, pp 380-384, 8 figs., May, 1907.

Dissections and sections of larvæ of *Bombyx mori* of various ages from just after hatching to the last instar show that the reproductive organs (ovaries or testes) are already in such an advanced stage of development that the distinction between male and female (testes and ovaries) can be recognized in larvæ from the time of the first moulting. Also that the just hatched larva has the reproductive organs already well developed. Careful scrutiny by a special student of oogenesis and spermatogenesis would probably enable him to determine the sex of the larva immediately on hatching.

The sex of the silkworm is then not to be tampered with by gorging or starving, and what is true of this lepidopteron is undoubtedly true of its cousins, the other moths and the butterflies. It is probably also true of other insects with complete metamorphosis. I recall dissections of various larvæ, notably of *Corydalid cornuta* (a neuropteran) and of *Holorusia rubiginosa* (a dipteran) in which the reproductive organs appear of two sizes in specimens of the same age: indeed in *Corydalid*, of two shapes. These organs need histologic examination. Some student should laboriously work through a long and representative series of insects and settle the question as to the time of sex differentiation. That is, find out whether it be true for all, as it is in the silkworm, that the time of sex differentiation is obviously before, or, at latest, at very little after the time of hatching. If it is true, the question of the influence of nutrition in sex determination will also be settled—for insects. And we need waste no more time in tedious feeding and tabulating.

Artificial Parthenogenesis in the Silkworm, in Biol. Bull., v. 14, pp 15-22., December, 1907.

In a clutch of unfertilized eggs oviposited by a virgin silkworm moth (*Bombyx mori*) almost always a small number of eggs begins development. This development extends to the formation of the embryonic envelopes and sometimes farther, and is clearly indicated to the observer by the change in color of the egg from yellow to cherry or through cherry to gray. Non-developing eggs

remain yellow and, after a while, collapse. Eggs which begin to develop either persist in spherical shape, which indicates persisting life, or collapse, which means death. The development of unfertilized eggs rarely proceeds, without artificial stimulus, beyond a very early embryonic stage. In fully 500 clutches or broods of unfertilized eggs (from confined females from isolated cocoons) under observation, not a single egg gave up its larva, although an average of about seven or eight per centum of the eggs began to develop.

Although this parthenogenetic development always ceases and the embryo dies before reaching hatching stage, much difference in vitality or duration of life of the egg (strictly, embryo) is noticeable. Some of the developing eggs collapse within a few days, some in a few weeks, while a few persist for several months. (The normal egg stage, *i. e.*, time from egg laying to hatching of larvæ in the silkworm univoltin races, is about nine months.) There is also to be noted a difference among races in the proportion of unfertilized eggs which begin to develop. Among a dozen races in our rearing rooms, one (a vigorous white-cocoon race called Bagdad) is strongly inclined to normal parthenogenesis, from twenty-five to seventy-five per centum, even in a few cases ninety-five per centum, of the eggs in unfertilized lots beginning to develop. The more usual proportion, however, *i. e.*, that shown by the other races, is, as already noted, less than ten per centum. So much for normal parthenogenesis in the species.

In 1885 Tichomiroff discovered that by bathing the unfertilized eggs with concentrated sulphuric acid, or by rubbing them gently, he could induce a considerably larger per centum than the normal to begin development. He repeated his experiments, confirming and extending his results, in 1902. By histologic examination of the eggs he learned that the artificially stimulated eggs which develop do so in a somewhat abnormal manner. Tichomiroff held the stimulus to development to be neither the action of specific ions, osmotic pressure nor catalysis. He believes that the eggs respond by segmentation to any appropriate excitation, "whatever the nature of this excitation."

Version, in 1899, used electricity as a stimulus, and found that the development thus initiated ceased at a point about corresponding with that reached by a fertilized egg on the third day after oviposition.

Quajat (1905) submitted unfertilized eggs to the action of oxygen, high temperatures, sulphuric acid, hydrochloric acid, carbon dioxide, and electricity. His account of the experiments indicates that he was able to stimulate development by several of these agents, but he gives no data to show the proportion of developing eggs in the various treated lots. No larva issued, but by an examination of the eggs he found that several embryos had practically completed their development and growth.

My own experiments include the treatment of something over a hundred lots of unfertilized eggs (a "lot" is all the eggs laid by a single female, averaging from 100 to 350 in number), and of several lots of fertilized eggs (to serve as controls to indicate possible injury to the eggs from the reagents used). The stimuli or agents used were dry air (obtained by drawing air through vessels of calcium chloride and then of concentrated sulphuric acid), high temperature, sunlight, friction, sulphuric acid, hydrochloric acid, glacial phosphoric acid, glacial acetic acid, absolute alcohol, potassium hydroxide, ammonia, and lime

water. The reagents were used in different dilutions and for varying lengths of time. The treatment was applied to eggs not more than twelve hours old; mostly to eggs but a few minutes to a few hours old. Five hundred or more lots of untreated, unfertilized eggs were observed in order to determine the extent of normal parthenogenetic development. The eggs of half a dozen silkworm races were used and all the eggs were preserved from time of laying until their death.

As it seemed to me that most of the favorable results obtained by Tichomiroff and Quajat were obtained by treatments which had as common effect a dehydration (such as high temperature, friction, sulphuric acid, etc.) I attempted to test this first by using various dehydrating agents, especially a dry chamber in which the eggs could be submitted for from a minute or two to several hours to a nearly perfectly dry atmosphere. Friction, heat, sulphuric acid, phosphoric pentoxide and glacial phosphoric acid were also used as dehydrating agents. At the same time other treatment, not dehydrating, was used on other lots and gave results hardly less favorable than the dehydrating. The results at the end of this first course of treatment seemed to point to the hydrogen ions as the most likely development-inciting factor. Hence various agents agreeing in containing hydrogen ions though differing radically in other particulars were used. The results gave no encouragement to the hydrogen ion theory. In fact I have not been able to come to an opinion concerning the true *causa efficiens* in the matter. My results simply show to me that various stimuli, acid or alkaline, dehydrating or non-dehydrating, possessing or not possessing hydrogen ions, are able to increase materially the proportion of eggs that develop in lots of unfertilized eggs.

The data of the experiments are given in considerable detail.

1. The first part of the document is a list of names and their corresponding addresses. The names are listed in a column on the left, and the addresses are listed in a column on the right. The names are: John Doe, Jane Doe, and John Doe. The addresses are: 123 Main St, 456 Main St, and 789 Main St.

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LELAND STANFORD JUNIOR UNIVERSITY PUBLICATIONS
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No. 2

THE
OPISTHOBRANCHIATE MOLLUSCA
OF THE
BRANNER-AGASSIZ EXPEDITION
TO BRAZIL

BY

FRANK MACE MACFARLAND

Professor of Histology
Leland Stanford Junior University

WITH PLATES I-XIX

STANFORD UNIVERSITY, CALIFORNIA
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Inheritance in Silkworms, I. Vernon Lyman Kellogg, Professor of
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CONTENTS

	PAGE
INTRODUCTION	5
LIST OF OPISTHOBRANCHIATE MOLLUSCA COLLECTED BY THE BRANNER-AGASSIZ EXPEDITION	6
LIST OF OPISTHOBRANCHIATE MOLLUSCA THUS FAR RE- CORDED FROM THE COAST OF BRAZIL	7
DETAILED DESCRIPTIONS OF THE SPECIES COLLECTED—	
1. Tethys dactylomela (Rang)	14
2. Tethys cervina Dall and Simpson	38
3. Pleurobranchus agassizii sp. nov.	59
4. Discodoris branneri sp. nov.	66
5. Discodoris voniheringi sp. nov.	73
6. Peltodoris greeleyi sp. nov.	84
7. Spurilla braziliana sp. nov.	91
LITERATURE CITED	100
EXPLANATION OF PLATES	105

THE OPISTHOBRANCHIATE MOLLUSCA OF THE BRANNER-AGASSIZ EXPEDITION TO BRAZIL.*

During the explorations of the Branner-Agassiz expedition to Brazil in 1899 a small collection of Opisthobranchiate Mollusca was made by Mr. A. W. Greeley, a member of the expedition. These were turned over to the writer for study, and the results obtained are embodied in the present paper. The Opisthobranchs of the Brazilian coast are but little known, no systematic effort having been made as yet to collect and study them, and it is only occasionally that reference to them is to be found in the literature upon the subject. Several shell-bearing Opisthobranchs have been described by various authors, but the naked members of the group have received but scant attention, and Von Ihering is practically the only author who has examined the Brazilian forms. His list and description of six species of Nudibranchs published in 1886, has remained for twenty years with but scanty additions.

The collection made by Mr. Greeley, though but small and made without any especial attention to the group, adds seven to the list of species thus far known from Brazilian waters, and is an indication of the results which careful and extended collecting in those regions might secure. Two shell-bearing Opisthobranchs were also found in the collection made by Mr. Greeley and studied by Professor W. H. Dall, and are listed in his "Mollusks from the Vicinity of Pernambuco," *Proceedings of the Washington Academy of Sciences*, III. 1891. p. 139-147. These are added to the list given in the present paper.

There is so little known about the structure of the Opisthobranchs from this region that a somewhat detailed examination of the collection in this respect has seemed warranted, especially since external characters afford so meagre a basis for classification in this group. Unfortunately the number of specimens secured is but small, so that, in most cases, the minute anatomical study was hampered by the lack of material. No notes save those

* Other reports upon the collections made by the Branner-Agassiz Expedition have appeared in Volume III of the *Proceedings of the Washington Academy of Sciences*.

of locality and date were taken by the collector, so that nothing can be given as to the color, or form of body in the living animal. In the study of the collection most of the specimens have been dissected, and many parts have been cut into serial sections, or otherwise prepared for microscopical study. All of these preparations, as well as the animals themselves, or what remains of them, are deposited in the Zoological Museum of the Leland Stanford Junior University, and their serial numbers are given under each species in the present paper.

The following is a conspectus of the seven forms discussed in the following pages.

Order OPISTHOBRANCHIATA.

Suborder TECTIBRANCHIATA.

Tribe Aplysoidea.

Family Aplysiidae.

1. *Tethys dactylomela* (Rang).
2. *Tethys cervina* Dall and Simpson.

Tribe Pleurobranchoidea.

Family Pleurobranchidae.

3. *Pleurobranchus agassizii* sp. nov.

Suborder NUDIBRANCHIATA.

Tribe Doridoidea.

Family Dorididae.

Subfamily Discodoridinae.

4. *Discodoris branneri* sp. nov.
5. *Discodoris voniheringi* sp. nov.

Subfamily Diaululinae.

6. *Peltodoris greeleyi* sp. nov.

Tribe Aeolidoidea.

Family Aeolididae.

7. *Spurilla braziliana* sp. nov.

The complete list of the Opisthobranchiate Mollusca of the Brazilian coast thus far described, together with those above listed is as follows. Those marked with an asterisk are deep water forms, i. e. 100 fathoms and over, and are of wide distribution throughout the Atlantic Ocean.

Order OPISTHOBRANCHIATA.

Suborder TECTIBRANCHIATA.

Tribe Bulloidea.

Family Actaeonidae.

1. *Actaeon cumingii* A. Adams.
Rio Janeiro, A. Adams, Proc. Zool.
Soc., London, 1854, p. 59.

Family Ringiculidae.

- *2. *Ringicula peracuta* Watson.
Off Pernambuco, 350 fathoms. Wat-
son, Challenger Gasteropoda, p. 636.
= *Ringicula nitida* Verrill. Dall,
Bulletin Museum Comp. Zool. Har-
vard, XVIII, 1889, p. 43.

Family Tornatinidae.

3. *Tornatina liratispira* Smith.
Rio Janeiro, E. A. Smith. Annals
and Magazine Nat. Hist., (4), IX,
p. 354.
4. *Tornatina canaliculata* (Say).
Anchorage off Fernando Noronha,
7-25 fath. Watson, Chall. Gasterop.,
p. 655.
- *5. *Retusa ovata* (Jeffreys).
Off Pernambuco, 350 fath. Watson,
Chall. Gasterop., p. 664.

Family Scaphandridae.

- *6. *Diaphana seguenzae* (Watson).
Off Pernambuco, 350 fath. Watson,
Chall. Gasterop., p. 646.
7. *Cylichna noronyensis* Watson.
Anchorage off Fernando de Noronha,
7-25 fath. Watson, Chall. Gasterop.,
p. 666.
8. *Cylichna bidentata* (d'Orbigny).
Canal de San Sebastiao, Von Ihering.
Revista Museu Paulista, II, 1897,
p. 169.

Family Bullidae.

9. *Bulla rubiginosa* Gould.

Near mouth of Rio Janeiro Harbor,
Couth. Gould, U. S. Exploring
Exp., XII, Mollusca and Shells,
1852, p. 221.†

10. *Bulla striata* Bruguière.

Canal de San Sebastiao, Von Ihering,
Revista Museu Paulista, II, 1897,
p. 169.
Mangosoules, Managuas, Maçeo.
Dall, Proc. Wash. Acad. Sci., III,
1901, p. 142.

Family Aceratidae.

11. *Haminea elegans* (Gray).

? *Bulla diaphana* Couthouy.
Rio Janeiro, Gould, Mollusca and
Shells, U. S. Exploring Ex., XII,
1852, p. 222.†

Family Hydatinidae.

12. *Micromelo undata* (Bruguière).

Goyana, on the reef. Dall, Proc. Wash.
Acad. Sci., III, 1901, p. 142.

Tribe Aplysoidea.

Family Aplysiidae.

13. *Tethys livida* (d'Orbigny).

Bay of Rio Janeiro. d'Orbigny, Voy.
dans l'Amérique Mérid., V, 3, 1835-
1843, p. 206.

14. *Tethys braziliana* (Rang).

Bay of Rio Janeiro. Quoy and Gai-
mard. Rang, Histoire Naturelle des
Aplysiens, 1828, p. 55.

15. *Tethys dactylomela* (Rang).

Maçeo, Alagoas. Pernambuco.

†The place of the original descriptions of *Bulla rubiginosa* Gould, and *Bulla diaphana* Couthouy, is given by Gould in his report upon the Mollusca of the U. S. Exploring Expedition as Proc. Boston Soc. Natural History, III, 1849, pp. 107 and 91 respectively. This has been cited in several recent works, e. g. by Pilsbry in Tryon's Conchology, XVI, pp. 330 and 356. I am unable to find any such description in any of the earlier volumes of the Proceedings, nor any earlier descriptions than the ones indicated above.

16. *Tethys cervina* Dall and Simpson.
Maçêio, Alagoas.
17. *Notarchus lacinulatus* (Couthouy).
Rio Janeiro Harbor. Gould, U. S.
Explor. Exp. Moll., p. 223.

Tribe Pleurobranchoidea.

Family Pleurobranchidae.

18. *Pleurobranchus agassizii* MacFarland,
sp. nov.
Riacho Doce, Alagoas.
19. *Pleurobranchaea inconspicua* Bergh.
Mouth of Cotinguiba River. Bergh,
Semper's Reisen, Wissenschaftliche
Resultate, VII: Malacol. Unters.,
IV, 1, 1, 1897, p. 49.

Suborder NUDIBRANCHIATA.

Tribe Tritonoidea.

Family Tritoniidae.

20. *Tritonia cucullata* Gould.
Coast of Brazil. Gould, U. S. Expl.
Exp. Moll., 1852, p. 308.
= *Marionia occidentalis* Bergh. Chal-
lenger Exp., X, 1884, p. 49, La Plata
and Buenos Aires.

Tribe Doridoidea.

Family Dorididae.

Subfamily Archidoridinae.

21. *Staurodoris verrucosa* (Cuvier).
Armação, Province Santa Catarina.
Von Ihering, Jahrb. deutsch. Mala-
kozool. Ges., XIII, 3, 1886, p. 230.
= *Staurodoris januarii* Bergh. Mal.
Unters., XIII, 1878, p. 583; Sup. H.
I, 1880, p. 37; System. 1892, p. 101.

Subfamily Discodoridinae.

22. *Discodoris branneri* MacFarland. sp.
nov.
Riacho Doce, Alagoas.

23. *Discodoris voniheringi* MacFarland.
sp. nov.
Riacho Doce, Alagoas.
- Subfamily Diaululinae.
24. *Thordisa ladislavii* (Von Ihering).
Armação, Prov. Santa Catarina. Von
Ihering, Jahrb. d. Mal. Ges., XIII,
3, 1886, p. 234.
25. *Thordisa dubia* Bergh.
Rio Janeiro Harbor, Rat Island,
Bergh, Bull. Mus. Comp. Zool.
Harvard, XXV, 1894, p. 178.
26. *Peltodoris greeleyi* MacFarland. sp.
nov.
Riacho Doce, Alagoas.
- Family Doriopsididae.
27. *Doriopsis atropos* Bergh.
Rio Janeiro. Bergh, Jahrb. d. D. Mal.
Ges., VI, 1879, p. 49.
- Tribe Aeolidoidea.
- Family Aeolidiadae.
- Subfamily Aeolidianae.
28. *Spurilla braziliana* MacFarland, sp.
nov.
Riacho Doce, Alagoas.
- Subfamily Favorininae.
29. *Phidiana selencae* Bergh.
Rio Janeiro. Bergh, Beitrage zur
Kenntniss der Aeolidiaden. VI.
Verh. d. k. k. zool.-bot. Gesellsch.
in Wien, 1878, p. 560.
- Family Pleurophyllididae.
30. *Pleurophyllidia muelleri* Von Ihering.
Armação, Prov. Santa Catarina, Von
Ihering, Jahrb. d. Mal. Ges., XIII,
3, 1886, p. 223.

In the above list the gymnosomatous and thecosomatous
Pteropods have been left out of consideration. Of the thirty

species enumerated, the Bulloidea are represented by twelve, the Aplysoidea by five, the Pleurobranchoidea by two, the Tritonoidea by one, the Doridoidea by seven and the Aeolidoidea by three, or nineteen Tectibranchs and eleven Nudibranchs as the total Opisthobranch fauna of some four thousand miles of coast line, extending from $4^{\circ} 22\frac{1}{2}'$ N. Lat. to $33^{\circ} 44'$ S. Lat. Of these all the Bulloidea and Aplysoidea are of wide distribution, many of them occurring throughout the North Atlantic, and others in the Antilles. It is readily seen from this that our information about the group in general, and the Nudibranchs in particular makes any theorizing as to distribution for the present somewhat premature.

The appearance of this paper, much of which has been in manuscript for several years, has been delayed by other duties. Six months spent at the Zoological Station at Naples in 1903 enabled me to compare and dissect the Mediterranean forms related to those discussed in this paper. I again take the pleasant opportunity of expressing my most cordial appreciation of the many kindnesses shown me while there by Professor Dohrn and his staff, as well as to the Smithsonian Institution for the grant of a table in the Station, which opened these privileges to me.

In the systematic arrangement of the Opisthobranchiata adopted in the present paper the plan of Pelseneer has been followed in the main. The characterizations of the different subdivisions have been more or less modified from those of Pilsbry, Pelseneer and Bergh in the majority of cases.

ORDER OPISTHOBRANCHIATA.

Marine Euthyneura with aquatic respiration; the ventricle of the heart is generally anterior, and the pallial cavity, when present, is widely open. There is a marked tendency to a reduction of the shell, which may become internal or disappear. In the naked forms spicules are sometimes developed.

SUBORDER TECTIBRANCHIATA.

Hermaphroditic opisthobranchiate Mollusca provided in the adult state with a mantle and shell, with certain exceptions; with one branchial plume and osphradium, with certain exceptions.

TRIBE I. BULLOIDEA.

Shell usually well developed, sometimes wanting, external or internal. Operculum seldom present. Pallial cavity well developed and containing the usually plicate ctenidium. Head usually without tentacles, and with dorsal surface forming a shield, usually separate from the neck, and with more or less scalloped margins. Edges of foot continuous with its ventral face and often modified into fins. Stomach usually with chitinous or calcified masticatory plates. Visceral commissure usually rather long. The monaulic genital duct usually connected with the penis by a ciliated groove.

TRIBE II. APLYSOIDEA.

Shell much reduced, more or less internal, or lost altogether in the adult state. Head with two pairs of tentacles. Margins of the parapodia separate from the ventral surface of the foot, and generally modified into natatory lobes. Visceral commissure usually very much shortened, except in Tethys. Genital duct monaulic, the hermaphroditic duct connected with the penis by a ciliated groove.

Family APLYSIIDAE.

Animal lengthened, not protected by a shell, the neck and head narrower than the body; mouth a vertical fissure; anterior angles of the head produced into two tentacular lobes folded above; behind them the cylindrical or conical rhinophores, slit above, in front of which are the minute eyes. Parapodia recurved over the back, forming two lateral or dorsal lobes enclosing the mantle and ctenidium. Genital orifice between the dorsal lobes, communicating by a long furrow with the eversible penis which is near the anterior right tentacle. Shell nearly or entirely covered by the mantle, uncoiled, in the form of a concave plate, sometimes absent. Mouth with corneous jaws and a large, multiserial radula composed of similar teeth; stomach armed with horny nodules; anus behind the branchial plume.

Subfamily APLYSIINAE.

Parapodial lobes well-developed, their anterior ends separated; genital orifice in front of the branchia; radula with wide, denticulate, rhachidian teeth, and narrower, serrate and denticulate laterals. Shell flexible.

Genus TETHYS Linné, 1758.

Tethys, Linné, Systema Naturae, 10th ed. 1758, p. 653.

Laplysia, Linné, Systema Naturae, 12th ed. 1767, p. 1089.

Aplysia, Gmelin, Systema Naturae, 13th ed. 1788, I, VI, p. 3103.

Tethys, Pilsbry, Proc. Acad. Nat. Sci., Philadelphia, 1895, p. 347.

Tethys, Pilsbry, Manual of Conchology, Tryon, XVI, 1896, p. 65.

Animal swollen behind, narrower in front, with rather long neck and head, bearing folded tentacles and slit rhinophores as usual in the family, the latter about midway between tentacles and dorsal slit. Parapodia arising in front of the middle of the animal's length, ample, freely mobile, free throughout their length, or united for a distance behind, functional as swimming lobes; anterior ends separated. Mantle nearly covering the ctenidium, having a median tube, foramen, or orifice communicating with shell cavity, and produced behind in a more or less developed

lobe or lobes, rolled to form an excurrent siphon. Genital orifice under front edge of mantle, in front of ctenidium; hypobranchial gland present, a short distance behind genital opening. Foot well developed.

Shell very thin, membranaceous, with a thin, calcareous inner layer, nearly as large as mantle, concave, with pointed, small apex, bearing a recurved lamina, and having a concave, posterior sinus.

This genus is usually known as *Aplysia*, an etymological correction by Gmelin of the name *Laplysia*, used by Linné in the 12th edition of the *Systema Naturae*. As pointed out by Pilsbry, the name *Tethys* is unmistakably applied to this genus by Linné himself in the 10th edition in 1758, and hence must stand, despite the common but erroneous usage.

Two species of this genus and one of *Notarchus* have already been recorded from the coast of Brazil, and to them are to be added the following two, already known from the Antilles.

***Tethys dactylomela* (Rang, 1828).**

Pl. I, Figs. 1-7; Pl. II, Fig. 8; Pl. III, Figs. 9-14; Pl. IX, Fig. 38.
Aplysia dactylomela Rang. *Histoire Naturelle des Aplysiens*, 1828, p. 56, pl. IX.

Tethys dactylomela (Rang). Pilsbry, in Tryon, *Manual of Conchology*, XVI, 1896, p. 75-76, pl. 32, figs. 16-19.

"Length about 17 cm. Always much swollen with elongated head and tail; rugose. Mantle or gill cover with a minute, central tube and a well developed siphon behind. Swimming lobes not united as far forward as the siphon.

"Color pale yellow of various shades, more or less covered in different individuals, with black rings, irregular and of various sizes. Inner sides of lobes and the mantle with large black spots of different forms. Borders of the swimming lobes tinged with violet.

"Shell large, much dilated, a little diaphanous, amber colored outside with a visible enamel within; posterior sinus deeply arcuate; beak recurved, triangular, thick and calloused. Altitude, forty-two millimeters."

EXTERNAL CHARACTERS.

Six specimens of this widely distributed Antillean species were found in the collection, five of them taken from the same locality, "Coral reef, Maceio, Alagoas, July 30, 1899," and the sixth from "Pernambuco stone reef, July 7, 1899," and collected in both cases by A. W. Greeley. No further notes accompanied the specimens, but, according to a verbal communication from Mr. Greeley, the preserved material was of nearly the same coloration as in life, the ground color being slightly deeper, a yellowish brown. The characteristic ink ejected on being disturbed was of a deep purple color. Of the six specimens taken, one was quite large, being over twice the length of any of the others, which were of nearly the same dimensions throughout. All were in a good state of preservation, but all more or less contracted, especially in the region of the mouth and head. The following table gives a comparison of the principal dimensions.

No.	Length	Width	Height	Length base of parapodia	Width space bet. ant. ends para- podia	Width space bet. post ends para- podia	Length of foot	Width of foot
1.	140 mm.	70 mm.	60 mm.	97 mm.	18 mm.	7 mm.	135 mm.	40 mm.
2.	70 "	40 "	50 "	55 "	17 "	18 "	60 "	18 "
3.	65 "	40 "	40 "	56 "	.....	3 "	63 "	20 "
4.	.....	.....	.....	56 "	9 "	5 "	.....	.....
5.	56 "	20 "	20 "	34 "	8 "	1.5"	40 "	18 "
6.	.....	.....	.....	.....	8 "	1.5"	.....	.....

In individual No. 3 the anterior end of the left parapodium was 10 mm. behind that of the right side. In individuals Nos. 4 and 6 the contraction of the head region was so great as to invalidate the measurements omitted in the table for all purposes of comparison.

Color. The general plan of coloration is the same as that given in the revised description of this species in Tryon's Manual of Conchology, Vol. XVI, p. 75, and quoted above. The black rings form a very striking color characteristic, their centers being free from pigment. They reach a diameter in the largest speci-

men of 7.0 mm., the band of pigment itself ranging up to 3.0 mm. in width. The inner surface of the parapodial lobes bears several branching bands of black, running in a generally vertical direction, near the thin margins, with occasional isolated blotches of pigment between them, and below merging into the black to greenish black area at the bases of the parapodia. Between the posterior ends of the parapodia is situated a median longitudinal dark band, which dilates posteriorly into a broad crescentic spot, the points of which are prolonged upward for a short distance along the inner face of the margins of the parapodia. The dorsal surface of the mantle is marked with irregular blotches of black, tending to form a series of incomplete rings. The under surface of the mantle is yellowish brown, the branchia brownish black, or nearly free from color.

Parapodia. The parapodia are prominent and high, their margins thin. The posterior half of the mantle is rolled into an erect tube, the siphon, the thin crenulate upper margin of which, in its slightly contracted state reaches just below the margins of the parapodia.

Shell. About midway of the length of the mantle in the median line is a single minute opening, borne upon a well marked, short cylindrical papilla, communicating with the shell sac, or mantle cavity. The shell is of good size, rather convex, very thin and translucent, but slightly calcareous, externally very pale yellow in color. In all the specimens unfortunately it was somewhat broken, the inner calcareous surface being reduced usually to fragments. The thin membranaceous margin of the shell projects beyond the calcified portion beneath, its anterior and right borders are rounded, the posterior border concave, the beak much thickened, triangular and recurved. In general it is similar to the figures of Rang for the species. Length 23 mm., width 16 mm., in an animal of 70 mm. total body length.

Tentacles. The tentacles and head region generally are more or less contracted in all the specimens. In the best preserved ones the posterior tentacles, or rhinophores are slender, auriform, the external slit being carried down posteriorly nearly to the base of the organ.

The anterior tentacles are much broader, stout, auriform, triangular in general outline, their outer margins being con-

tinued downward to the mouth, the tips auriculate, their posterior margins forming a prominent flap closely applied to the anterior portion.

Just below and in front of the bases of the rhinophores the minute black eyes shimmer through the integument.

Reproductive opening. The male genital opening lies just below the base of the right anterior tentacle, a strongly defined groove extending backward from it and dorsally between the parapodia to the hermaphroditic orifice in front of the base of the branchia. This groove is marked by a narrow black line on its right margin throughout its whole length. Behind and below the genital opening is a large conspicuous circular orifice, the opening of the hypobranchial gland, or gland of Bohadsch.

The anal opening is situated upon the base of the posterior wall of the siphon, presenting a pocket-like appearance.

The renal opening is small and slit like, 1.2 mm. in length, and lies deep in the mantle cavity above the posterior end of the ctenidium, some distance in front of the anus.

Foot. The foot is broad and well developed, its anterior end rounded, the posterior one more bluntly pointed. Its margin is clearly defined in all the specimens, its well developed musculature being contracted, giving it a firm rugose texture, in contrast to the smooth soft surface of the remainder of the body.

In the literature scarcely anything is to be found upon the internal anatomy of this species, a fact too frequently true of the majority of the members of this family, many of them having been described by the shell alone, which, as Pilsbry has pointed out, is probably the least characteristic organ of the animal. The interrelations of this widely distributed group cannot at present even be approximated on account of this lack. With a view to aiding in filling up this gap in our knowledge I have made detailed dissections of the Aplysiidae found in this collection.

INTERNAL ANATOMY.

In the description of the internal anatomy, unless otherwise stated, all of the measurements given are taken from an individual of 70 mm. total length in the well preserved alcoholic specimen.

The body wall is similar to that of other members of the group, the external integument being reinforced by interlacing

bands of strong muscle fibres. The body cavity is roomy, and nearly filled by the viscera, its pseudo-peritoneum being colorless or slightly yellowish in hue.

ALIMENTARY SYSTEM.

Pharyngeal bulb. The mouth communicates by a very short tube with the pharyngeal bulb, a strong, muscular organ of conical form. Its length is 11.0 mm. with a maximum diameter of 10.0 mm. Opened from above the deep, rich amber-colored radula is exposed, and in front of it, upon each side, the mandibular plates of a similar color. The latter are situated at the anterior end of the pharyngeal bulb, almost completely encircling the opening and nearly touching each other above and below. The opalescent lip disc is elliptical in outline, the opening appearing as a vertical slit, 4.0 mm. in length, while immediately within it the margins of the mandibular plates are seen. These plates are roughly rectangular in outline (Pl. I, fig. 7), their length being 5.5 mm. and their breadth 3.0 mm. The posterior margin is bounded by a sharp, regularly curved line of opalescent hue, while the anterior margin is irregular, and more or less jagged and worn. Each plate is made up of densely packed rodlets, nearly straight, or slightly bent, and of approximately the same diameter throughout their whole length. At the posterior margin of the plate the arrangement of these rodlets may be easily seen (Pl. III, fig. 12), but in the anterior portion such an arrangement cannot be made out clearly, owing to the overlapping of the rodlets as they increase in length. The shorter rodlets are flattened antero-posteriorly, with a strong tendency to the formation of a slight concavity, or longitudinal groove upon the posterior face, and a corresponding convexity in front. Their average, greatest width is 0.005 mm. Toward the anterior border the rodlets increase in length, their basal diameter remaining nearly the same, while the length may reach 0.124 mm. The outer extremity is bluntly rounded, the distal one-third being sometimes slightly enlarged, or club-shaped, or, in other cases, entirely straight throughout (Pl. III, fig. 13). The bending and distortion, incident to microscopic preparation as a whole mount, indicate a considerable degree of flexibility.

Radula. The radula is broad, deeply grooved behind, and of

a dark amber color. As is usual the anterior rows of teeth are very much worn and broken, so that even their number is uncertain. About eleven such imperfect rows may be made out, which gradually pass over into forty-seven complete rows, of which the last twenty are still inclosed in the radula sheath. The total number of rows is thus about fifty-eight. The greatest length of the radula is 9.0 mm., and its greatest width 3.0 mm.

The number of teeth varies in the different rows, being quite small in the most anterior rows, and increasing regularly in the succeeding ones to 26:1:26 in the twenty-fifth row, and 38:1:38 in the fifty-fifth one. In the anterior twenty to twenty-five rows the teeth are much worn, scarcely any being perfect, the cusps being usually blunted, or broken entirely away. Typical teeth, taken at intervals across the radula from neighboring rows, are shown in figs. 1, 2 and 3, of Pl. I. Fig. 1 represents the median and first lateral teeth of the 49th and 50th rows; fig. 2 shows the 8th, 9th and 10th teeth of the same rows, while figs. 3 and 4 give the 18th to 20th of the 50th row and the 32d to 37th teeth of the 54th row respectively all under the same magnification. The rhachis bears a single large tooth in each row. Its base is broad and trapezoidal in form, the broader end being directed posteriorly. It varies but slightly in size throughout the length of the radula, averaging 0.216 mm. in the diameter of its broader posterior end and 0.06 mm. in the diameter of its anterior end, with a length of 0.156 mm. In the anterior end of the radula the base is often divided longitudinally, or a thinning away of the median line may indicate such a division as incomplete. The posterior margin is very slightly concave, the anterior one deeply emarginate, the notch being carried up on the back of the hook as a deep groove. The anterior end bears a strong hook, which is as broad as the full width of the base at its anterior end. The length of this hook averages 0.126 mm., seven-twelfths the length of the base. It terminates in a large median blunt cusp, and two much smaller lateral cusps. The sides of the median cusp bear from four to ten thin irregular denticles on either side in the posterior portion of the radula. These denticles are either separate or, more usually, united at their bases. In the anterior portion these denticles are either worn away or undeveloped. The lateral cusps (Pl. I, fig. 1), are

one-fourth to one-half the length of the median one, and, in the last few rows may bear very minute serrulations, chiefly upon their outer margins.

The pleural teeth are rather uniform in outline, the innermost and outermost being slightly smaller than the remaining ones, into which they pass in a graded series. The general form of the pleural teeth is shown in Pl. I, figs. 5 and 6, in dorsal and lateral view. The base is broadest and thickest at its anterior end, tapering to a rounded posterior one which is produced strongly toward the outer border of the radula. In the posterior portion of the radula the base is broader throughout than in the anterior region. The same lateral prolongation is shown throughout the whole length of each row, being most strongly marked about the middle of each (Pl. I, fig. 3). The anterior end of the base is recurved dorsally in a strong, broad hook, projecting upward at an angle of about 45° and bearing two strong unequal cusps, which are about as broad as long near the innermost ends of the row, and increase in length progressively until they become about two and one-half times as long as broad, a proportion reached by the tenth tooth (Pl. I, figs. 1, 2). The smaller external cusp measures one-half to one-third the length of the larger, and is of the same general form. Both cusps bear typically a varying number of well marked irregular denticles upon their margins, which may be entirely separate, or, as is usually the case, are united at their bases into a thin marginal band. These denticles may be fairly uniform in size and shape (Pl. I, fig. 2, 10), or more often, very irregular (Pl. I, figs. 2, 3). The small external cusp bears a lesser number of denticles, which may be few and small, or large and irregular, often attaining such a size as to give the cusp the appearance of being divided (Pl. I, fig. 3). The dimensions of a typical large pleural tooth are: length of base, 0.288 mm., greatest width of base, 0.108 mm., length of larger cusp, 0.102 mm., length of smaller cusp 0.042 mm. The external pleurae decrease progressively in size outwards, the outermost two or three in many cases being reduced to the base alone, the recurved hooks being undeveloped (Pl. I, fig. 4).

Dobson in the Journal of the Linnaean Society (XV, 1880, p. 159), figures several teeth from *Tethys dactylomela* which agree

in general with those here given. Eliot, in his "Notes on Tectibranchs and Naked Mollusks from Samoa," Proc. Philadelphia Academy, 1899, p. 515, states that the radula of a *Tethys dactylomela* examined by him possessed a unicuspid central tooth, the laterals having an inner, but no outer cusp, a condition decidedly different from that described above in the specimens which I have examined.

Salivary glands. The ducts of the salivary glands emerge from the buccal mass on its posterior surface on either side of the anterior end of the esophagus. The glands are long flattened strap-shaped structures, 1.5 mm. in greatest width. They pass through the esophageal collar formed by the central nervous system, extend backward along the left side of the visceral mass, the left one above, and dwindle away posteriorly, their tips being attached to the sides of the anterior portion of the first tritulating stomach, the tip of the left one being situated dorsally, that of the right one ventrally.

Esophagus and stomach. The esophagus is a short broad thin-walled tube about 6.5 mm. in length, dilating posteriorly into the capacious stomach. Its inner surface is smooth, save for a few low longitudinal ridges. In the stomach may be distinguished three divisions. The first, or ingluvies, is everywhere very thin walled, its inner surface is smooth and passes gradually into that of the esophagus in front. In all the specimens examined the ingluvies was greatly distended with fragments of algae. In its lower posterior portion the ingluvies suddenly constricts into the "first tritulating stomach" of Mazzairelli, clearly marked externally by its strong muscular wall, the fibres of which are mainly arranged in a circular direction. The width of this band varies from 11.0 mm. to 18.0 mm. in the specimens examined, the diameter of the contracted stomach at this point ranging from 15.0 mm. to 20.0 mm. Borne upon the inner surface of this wall is a series of strong horny pyramidal teeth of a light amber color. The sides of these teeth are formed by four roughly triangular faces, and, the two anterior ones being larger than the two posterior ones, the tip of the tooth is, in consequence, inclined backward. The teeth are borne upon plate-like elevations of the epithelium, corresponding in shape to the bases of the teeth. In alcoholic material the teeth are readily separable

from these elevations. The largest one of the basal impressions thus left measured 6.0 mm. in length by 5.0 mm. in width. The teeth are arranged in a sort of quincunx in about six transverse rows, the larger ones occupying the middle and posterior portion, and in front of these the smaller ones are alternately arranged. The largest of these teeth measured 4.0 mm. in height. In the contracted state of this portion of the stomach, the apices of these teeth meet in the center of the lumen and fit closely together, thus nearly closing the opening.

Succeeding this first triturating stomach is a somewhat wider and longer, much thinner walled division of the alimentary canal, the "second triturating stomach" of Mazzairelli. Its walls are much less muscular than those of the first stomach, being of practically the same thickness as those of the ingluvies. Instead of bearing numerous small teeth as in those Mediterranean species studied by Mazzairelli ('93), the teeth are reduced to a single series arranged in a transverse row, about midway of the length of the organ. These teeth are very small and readily dehiscent; their basal impressions are nearly round in outline, and about 0.7 mm. in diameter. There are seven such impressions in the first specimen dissected, six and eight in others, arranged in a transverse row, and occupying about one-half of the total circumference of the whole organ. The remainder of the lining of the second stomach is entirely smooth.

Posterior visceral complex. The hinder portion of the second stomach is situated between the two anterior lobes of the large liver, thence passing rather abruptly into the intestine. The posterior visceral mass is made up of the liver, the intestine and the hermaphroditic gland, and is broadly conical in general form, the apex being directed posteriorly, and the elliptical base lying against the posterior part of the stomach and partially inclosing it. It is covered by a delicate membrane of connective tissue, the peritoneal lining of the pseudo-coelom. The intestine is very thin walled, and is filled with finely divided detritus of algal nature. It describes a series of complicated loops upon the liver, in the surface of which it is imbedded. The intestine enters the liver at its lower border, passes backward, thence upward and forward describing a long loop upon the upper surface of the liver toward its right side, to return again to the left, from which

it passes in a sinuous course to the anus, situated upon the posterior wall of the siphon. At the beginning of the intestine its dilated lumen receives two large biliary ducts, which ramify throughout the substance of the liver. Two low ridges, bounding a shallow groove, lie along the intestinal wall in contact with the liver, near the beginning of the tube. These may be followed backward into a long curved blind tube, in the wall of which they become overlapping elevations, dividing it into two longitudinal chambers which are in communication at the end of the tube. This, the hepatic coecum, is imbedded in the substance of the liver throughout nearly its whole length, but its blind termination reappears at the surface as a small rounded area, which might readily be mistaken for a portion of the wall of the intestine. The coecum describes a C shaped loop of nearly 10.0 mm. in length with a fairly constant diameter of 1.5 mm.

CENTRAL NERVOUS SYSTEM.

The ganglia. The central nervous system of *Tethys dactylomela* (Pl. II, fig. 8) is made up of eight paired ganglia grouped around the anterior end of the esophagus, close to its origin from the pharyngeal bulb. These are the cerebral, the pleural, the pedal and the buccal ganglia, the right and left components of each pair being united by commissures, while the ganglia of each side are united by the cerebro-pedal, the cerebro-pleural, the cerebro-buccal and the pleuro-pedal connectives. In addition to these centrally located ganglia, there are others, more or less distant from the central system. Chief of these are the parieto-visceral, the genital, and the ganglia of the anterior and the posterior tentacles. The central nervous system is closely enveloped by a capsule of connective tissue in a firm sheath, which renders the dissection of the nerves a matter of some difficulty. The ganglia, their commissures, connectives and nerves will be taken up in order in the following description. The figures and descriptions given by Von Ihering ('77), Mazzarelli ('93), and Vayssi re ('85), based upon European species of *Tethys*, vary so much from the results which I have obtained in *Tethys dactylomela* and in *T. cervina* that considerable detail seems to be justified in the following account. In fig. 8 of Pl. II I have endeavored to give an accurate representation of the central nervous system

of this species in dorsal view, the abbreviations in the following description all referring to this figure. The nerves are numbered rather arbitrarily in the order of their origin from the ganglia, from above and in front, downward and backward, the relative peripheral distribution not being primarily considered in this arrangement.

Cerebral Nerves. The cerebral ganglia (*cer. g.*) are situated upon the dorsal side of the esophagus at its anterior end, and are so closely applied to each other that the cerebral commissures connecting them are very short, the two ganglia being practically fused together in the median line into a single mass. They are rounded, and flattened upon their dorsal surface, and fit closely down upon the underlying esophagus. From the sides of the ganglia, close up to the origin of the fifth nerves, arise the strong cerebro-buccal connectives, (*c. b. con.*), which curve downward, around the esophagus, to the buccal ganglia. Below and behind the origin of these arise the cerebro-pedal connectives, (*c. p. con.*), which pass downward and outward to the large pedal ganglia, (*ped. g.*), beneath the esophagus, and, close to the origin of the latter pair, the equally stout cerebro-pleural connectives (*c. pl. con.*) are given off. These pass downward, outward and backward, and terminate in the small pleural ganglia (*pl. g.*), resting upon the upper border of the pedal ganglia.

From the cerebral ganglia arise six pairs of nerves, the origin and distribution of which is the same for both sides, unless otherwise noted in the following description.

The first nerve (*c1*) is a strong one, arising from the anterior border of the ganglion, passing forward over the pharyngeal bulb, and is distributed to the skin and muscles in the region of the mouth.

The second nerve (*c2*), is broad and strong, arising immediately behind the first. After a short course it bifurcates, its more slender external division passing to the anterior tentacle, and terminating in a small ganglion at its distal extremity. The stout inner branch splits up into a number of smaller branches, all terminating in the integument in the neighborhood of the mouth.

The third nerve (*c3*), arises immediately behind the first, but more dorsally. It is more slender, and passes to the rhino-

phore, giving off a few delicate branches to the integument near its base, and terminating in a small ganglion at its distal extremity.

The fourth, or optic nerve (*c4*), is very slender and quite long. It arises immediately behind and exterior to the third, and is inclosed in a common sheath of connective tissue with it for a very short distance, much less than that described by Mazzarelli for the Mediterranean species. It is unbranched, and passes directly to the eye. No trace of an optic ganglion can be made out at its base with the dissecting microscope, though sections might show its presence.

The fifth nerve (*c5*), arises from the lateral border, immediately in front of the cerebro-buccal connectives and is rather slender. On the left side it courses forward and is distributed to the body wall in the region of the mouth. Its fellow of the right side passes forward, and divides into two branches, one of which is soon lost among the muscles of the body wall, immediately below the anterior portion of the penis. The second, more slender branch courses forward, parallel to the penis, giving off three branches at intervals, which pass to the latter organ, the main nerve being finally distributed to the muscles of the mouth region.

The sixth pair form the acoustic nerves. They are included in the cerebro-pedal connectives for about one-half of their length, and then become separate from them as very delicate nerves, passing directly to the otocysts, rounded capsules lying close to the bases of the cerebro-pedal connectives upon each side. These nerves are not shown on Pl. II.

Pedal ganglia. The pedal ganglia (*ped. g.*), are the largest of the central nervous system, 3.0 mm. in greatest diameter, approximately circular in general outline, flattened upon the antero-ventral surface and strongly arched upon the postero-dorsal face, thus having a nearly hemispherical form. They are united below the esophagus by a stout, transverse commissure, (*p. com.*), 3.0 mm. in length, and 1.0 mm. in diameter. This is inclosed within a broad, flattened sheath of connective tissue, which also contains near its upper anterior margin a very delicate subcerebral commissure, connecting the cerebral ganglia together below the esophagus. This latter commissure is so fine that it is made out with certainty only in transverse, serial sections of

the whole band. From the ventro-posterior margin of each pedal ganglion a much more slender parapedal commissure (*p. p. com.*) arises. It is 7.0 mm. in length, being more than double that of the thicker pedal commissure, and describes a posteriorly directed loop below the esophagus. Somewhat to the left of its middle point a long slender unpaired nerve (*a*) is given off, in one case being formed by a union of a short branch from each side of the loop, in others coming from the left side alone. It passes backward and is distributed to the pedal artery and foot.

From the pedal ganglia arise ten pairs of nerves, which show such differences in the two sides that they are here described separately.

Left pedal nerves. The first nerve (*p.1*), is quite slender. It arises from the upper outer border of the ganglion and passes backward and is distributed to the peritoneum and muscles of the posterior dorsum.

The second nerve (*p.2*), arises close below the first and is of similar size. It bifurcates close to the ganglion, one of the rami thus formed passing backward to a similar distribution as that of the first nerve; the other ramus divides into (*a*) a branch curving forward and forming an anastomosis with a branch of the second pleural nerve, described below, and (*b*) a second branch which is distributed to the muscles of the dorso-lateral region.

The third (*p.3*), is a rather slender nerve arising just below the first and second, and more upon the anterior face of the ganglion. In one instance it appeared as two nerves very close together. It branches to the integument and muscles of the dorsal wall above the pharyngeal bulb, one branch passing undivided to the region of the eye.

The fourth nerve (*p.4*), arises from the lateral margin of the ganglion, is rather long and strong, passing backward to its distribution in the anterior portion of the parapodium.

The fifth (*p.5*), is a strong nerve from the mid-lateral margin of the ganglion. It soon divides into three branches, the anterior one of which passes to the muscles of the body wall, the other two to the parapodium.

The sixth nerve (*p.6*), is the largest of the pedal group. It arises close to the root of the fifth, and from its distribution is

termed the posterior pedal nerve. It soon divides into two main branches of unequal size, which pass backward and ramify to the posterior portion of the foot, giving off a few slender branches to the mid-lateral region of the same.

From the ventro-anterior face of the ganglion, near the entrance of the cerebro-pedal connectives arises a very slender nerve, the seventh (*p.7*). A short distance below it, and from the same face, the ninth nerve (*p.9*), is also given off. These two nerves are closely enmeshed in the capsule of connective tissue enveloping the posterior end of the pharyngeal bulb, and may be easily overlooked. A short distance from their origin they are connected by an anastomosis, and beyond this the two have a similar distribution, branching richly to the peritoneum, the aorta, and the muscles of the dorso-lateral wall of the body.

The eighth, or median pedal nerve, (*p.8*), arises at the outer lower margin of the ganglion, passes outward and backward, dividing into two nearly equal rami, which are distributed to the median region of the foot.

The tenth, or anterior pedal nerve (*p.10*), is the lowermost one of the series. It is of about equal caliber to the eighth, and divides into three main branches which curve forward to the anterior portion of the foot.

Right pedal nerves. The first pedal nerve (*p.1*), arises as a slender process from the outer upper margin of the ganglion, and soon divides into two unequal branches. The larger of these passes directly to the muscles of the lateral wall. The other branch subdivides again, in a short distance, into an anterior and a posterior branch. The posterior one of these innervates the penis, the anterior one runs parallel to the latter organ, gives off two or more delicate twigs to it, which anastomose with the subdivisions of the posterior branch, the main trunk terminating in the muscles of the mouth region on the right side.

The second and third nerves are closely associated at their origin, some individuals showing them as separate nerves, while others show the two united as a single nerve for a very short distance. In fig. 8 of Pl. II I have shown the separate condition. In *Tethys cervina*, as will be seen, the united condition was found, and further comment will be made in the description of the central nervous system of that form.

The second nerve (*p.2*), arises slightly in front of and below the third, in the instance figured on the plate, passes outward and gives off a branch which forms an anastomosis with the nerve from the right pleural ganglion described below. The main branch passes to the lateral retractor muscle of the head, a slender branch also being distributed to the dorso-lateral wall.

The third nerve (*p.3*), is usually stronger, and is much longer, coursing backward. It sends one branch to the muscles of the dorsum, another farther on to the muscles and integument of the side, a third to the Organ of Bohadsch, or hypobranchial gland, and, after giving off one or two branches to the muscles of the body wall, finally terminates in the right parietal ganglion, thus forming a pedo-parietal connective. The branch given off to the Organ of Bohadsch also forms an anastomosis with a recurrent branch from the second nerve of the *left* visceral ganglion, to be described farther on.

The fourth (*p.4*), is a moderate nerve in diameter but quite long. It arises from the right margin of the ganglion, courses backward, and is distributed to the right parapodium, like its fellow of the opposite side.

The fifth nerve (*p.5*), arises close in front of the root of the sixth from the median margin of the ganglion. Its strong trunk soon splits into three nearly equal subdivisions, the most anterior one of which is distributed to the body wall in front of the parapodium, the remaining two ramifying in the parapodium itself.

The sixth, or posterior pedal nerve, (*p.6*), is, as on the left side, one of the largest nerves from the ganglion. Its origin and relations are similar to those of its fellow, which is also true of the eighth (*p.8*) and tenth (*p.10*), the median and anterior pedal nerves respectively. In the last named there is a slight tendency to variation in the number of the main branches close to the ganglion, but otherwise these nerves present no great differences on the two sides, nor in different individuals.

Close to the root of the eighth nerve and a little behind it, on the outer, posterior face of the ganglion is found the origin of the parapedal commissure (*p. p. com.*). Upon the left side this commissure originates from the inner ventral margin of the ganglion.

The seventh (*p.7*), and ninth (*p.9*), nerves, like the cor-

responding nerves of the left side, arise from the ventro-anterior face of the ganglion, and present some difficulty as to their exact numerical order with respect to the other nerves of the same ganglion. They are also closely bound up in the connective tissue sheath surrounding the end of the pharyngeal bulb. The seventh nerve is slightly larger than the ninth, and is distributed mainly to the penis, and the body wall in the immediate neighborhood of that organ. It also forms a strong anastomosis with a branch of the ninth, as is shown in the fig. 8 of Pl. II. The ninth nerve is distributed mainly to the muscles of the body wall below the lateral retractor of the head.

Pleural ganglia. The pleural ganglia (*pl. g.*), the "proto-visceral ganglia" of Mazzarelli ('93), are quite small, 1.0 mm. in diameter, and nearly spherical. They are situated upon the upper posterior face of the pedal ganglia, and are connected with them by the extremely short pleuro-pedal connectives. From the posterior surface of the left pleural ganglion arises the long and strong pleuro-visceral connective (*pl. v. con.*), while from a nearly similar position upon the pleural ganglion of the right side is given off the pleuro-parietal connective (*pl. par. con.*), nearly equal in length. These two connectives pass directly backward, converging to terminate in a pair of ganglia, the parieto-visceral ganglia, lying on the inner surface of the dorsal body wall at a point midway between the anterior bases of the pleuropodia and close to the anterior insertion of the mantle.

The pleural ganglia are usually described, e. g. by Mazzarelli ('93, p. 108), as not giving off any nerves in the Aplysiidae. But in *Aplysiella petalifera* Rang Pelseneer ('94) describes a lateral nerve arising from each pleural ganglion and forming an anastomosis with a pedal nerve of the same side, which condition, he further states, also exists in certain species of Aplysia and the Gymnosomata. Vayssi re ('85) describes and figures a nerve from each lateral visceral (pleural) ganglion in *Notarchus punctatus* Philippi, which is associated in a part of its course with a pedal nerve to the mantle, and is distributed to the lateral tissues of the body on the right side, at the base of the branchia. Whether an anastomosis of these two nerves occurs or not does not appear from his description. In the two species of Aplysiidae from Brazil unmistakable though slender nerves do arise from the

pleural ganglia, and equally unmistakable anastomoses occur with a pedal nerve in each case. These relations will be taken up in their order.

Left pleural nerves. From the outer upper margin of the left pleural ganglion arise two nerves (*pl. 1*, *pl. 2*) close together, and are closely enmeshed in the capsule of dense connective tissue surrounding the central nervous system. They are both distributed to the muscles of the lateral and dorsal body wall in the immediate vicinity of the ganglion. The second of these nerves is connected by an anastomosing branch with the second pedal nerve of the same side as is seen in the figure.

Right pleural nerves. From the right pleural ganglion a single, fair sized nerve arises (*pl. 1*) below and in front of the origin of the pleuro-parietal connective. It passes outward and forms an anastomosis with a branch of the second pedal nerve (*p. 2*) of the right side. The double trunk thus formed then breaks up into a number of branches in the peritoneal membranes and in the dorso-lateral wall of the body.

Buccal ganglia. The buccal ganglia (*buc. g*) are nearly vertically placed upon the posterior face of the pharyngeal bulb just below the beginning of the esophagus (Pl. III, fig. 9) and present an anterior slightly concave face in contact with the bulb, and a posterior arched one, turned away from it. These ganglia are plump rounded bodies of an elliptical outline, slightly flattened, and closely united in the median line by a broad and very short commissure. On Plate II the buccal ganglia are shown in their relations with the remainder of the central nervous system; in figures 10 and 11 of Plate III they are shown isolated in ventro-posterior and dorso-anterior views respectively. The short strong cerebro-buccal connectives (*c. b. con.*) unite them to the cerebral ganglia above, being inserted laterally upon the posterior surface, between the bases of the second and third buccal nerves (Pl. III, figs. 9, 10 and 11), and curving laterally upward to the cerebral ganglia. All the nerves of the buccal ganglia bear small white pigment spots arranged in a single series at regular intervals along their proximal portions.

Buccal nerves. In the description following the numbering of the nerves follows their order of origin from the anterior end of the ganglia backward, an order followed by Mazzarelli on p.

107 of his *Monografia*, but the notation of his fig. 9, tav. IV does not follow the same, nor is there any reference made to the figure in the description.

The first nerve is a strong, unpaired, median one arising upon the dorsal, median region of the group by the union of a large bundle of fibres from each ganglion (Pl. III, fig. 11, 1). It almost immediately bifurcates into two equal subdivisions which pass directly into the pharyngeal bulb, and are distributed to the muscles of the rotella, bearing the radula.

The second nerve (Pl. III, figs. 9, 10, 11, 2), arises antero-laterally and courses around the external face of the pharyngeal bulb to the attachment of the lateral M. retractor bulbi. Here it divides into two branches, the posterior one passing directly inward, ramifies among the deep muscles of the radula, while the anterior branch courses forward and is distributed to the M. ant. lateralis bulbi, and to the deeper muscles of the bulb.

The third nerve (Pl. III, figs. 9, 10, 11, 3), arises close above the base of the second nerve and passes around the side of the bulb above and diverging slightly from it. At the posterior border of the M. antero-lateralis bulbi it forks and passes beneath that muscle, giving off branches to it as it passes deeper into the bulb. It may be traced forward to the anterior end of the bulb, where its delicate branches are finally lost among the deeper, circular muscle fibres.

The fourth nerve (Pl. III, figs. 9, 10, 11, 4) arises from the lateral margin of the ganglion, behind and above the origin of the third, and passes upward over the postero-dorsal face of the pharyngeal bulb, following closely the external border of the proximal portion of the salivary gland to the appearance of its duct at the surface of the bulb. Near this point it penetrates the outer layers of the muscular wall, and passes forward in it to the anterior end of the bulb, giving off numerous branches to the muscles of the dorsal portion.

The fifth nerve (Pl. III, figs. 9, 10, 11, 5) is quite small, and may be readily overlooked, or considered as a branch of the sixth one. It arises close to the base of the latter, between it and the fourth, and, on the left side, seems indeed to be a basal branch of the sixth in many cases (Pl. III, fig. 10, 5). On the right side, however, it is distinct in origin. It is probably to be

regarded as a salivary branch of the sixth, as it is distributed to the salivary gland, and thus would correspond to the branch shown by Mazzarelli in the Neapolitan forms as arising well up from the base of that nerve.

The sixth nerve is a strong and important one. It corresponds to No. III of Mazzarelli's text, and to No. 4 of his fig. 9, tav. IV. It is shown in figs. 9, 10 and 11, of Pl. III as arising from the posterior margin of the buccal ganglion, and bifurcating after a short course. Its anterior division soon gives off a median branch which breaks up in the wall of the esophagus, while the remainder continues forward between that organ and the salivary gland, giving off slender branches to each, and is finally distributed to the roof of the pharyngeal cavity at the beginning of the esophagus. The posterior division of the sixth nerve forms the esophageo-gastric nerve of each side. It courses backward along the esophagus, over the ingluvies, giving off fine branches at intervals to its walls. At the anterior boundary of the first tritulating stomach these two main lateral trunks, together with several of their branches, unite in a circular plexus of fibres around the anterior margin of this division of the stomach. From this plexus, in which no ganglionic enlargements were found, nerves pass into the wall of the digestive tube, and several (six or more) branches course backward to the second tritulating stomach, in the wall of which they branch and anastomose irregularly, and thence are continued further back along the intestinal tract in a similar manner.

Parieto-visceral ganglia. The position of the parieto-visceral ganglia, the "deuto-visceral ganglia" of Mazzarelli ('92) has been mentioned above in connection with the pleural ganglia. The two ganglia (Pl. III, fig. 14), are completely fused together, forming a pear shaped mass, and show indications of their double nature at their anterior end alone, at the entrance of the two connectives. The right, or pleural ganglion is uppermost, lying directly above the left, or visceral ganglia. From them are given off the following important nerves.

Visceral nerves. From the left visceral ganglion arise three nerves. The first of these (*l. v. 1*), is the smallest. It originates from the postero-dorsal side of the ganglion, and, dividing into

three main branches, is distributed to the vesicle of Swammerdam and its duct.

The second (*l. v. 2*), is a strong, flattened nerve from the posterior right side of the ganglion. It passes backward along the body wall, giving off a branch to the liver, another to the large hermaphroditic duct, a third which soon bifurcates, one subdivision being distributed to the dorsal peritoneum and muscles, the other, recurving forward, gives off a number of delicate branches to the dorsal peritoneum and muscles, and itself anastomoses with a branch of the third right pedal nerve, the united nerves sending a branch to the posterior face of the Organ of Bohadsch. The main trunk of the nerve continues backward, penetrates the dorsal body wall, and bifurcates to the anal portion of the alimentary canal and to the walls of the siphon.

Close to the left of the second nerve arises an equally strong nerve, very soon dividing into two main trunks, which pass backward, diverging from each other. In the largest specimen these two trunks arose as separate nerves from the ganglion. The left one (*l. v. 3a*), of these sends a branch to the liver, a more slender one to the muscles of the dorsal body wall, while the main trunk curves upward around the posterior wall of the pericardium, and thence forward in its dorsal wall, and is distributed to the heart and the kidney. The right main branch (*l. v. 3b*), of the third nerve sends a branch to the liver, another to the large hermaphroditic duct, and, crossing the base of the adnexed genital mass, gives off a branch to the small genital ganglion lying upon it. Crossing the small hermaphroditic duct, it gives off two branches to it, and, continuing backward, finally terminates among the muscles in front of the posterior portion of the alimentary canal.

Parietal nerves. From the right, or parietal ganglion arise two nerves. A short distance behind the junction of the pleuro-parietal connective with the anterior end of the parietal ganglion the first nerve (*r. p. 1*), is given off. It is a small trunk, sending a number of branches to the region of the genital opening, while another branch (*1a*), courses forward and unites with a branch of the third pedal nerve, thus forming a parieto-pedal connective. In one individual the branch of the third pedal nerve continued on to unite directly with the parietal ganglion, close to the entrance

of the pleuro-parietal connective, simply receiving a small anastomosing branch of the first parietal nerve.

The second (*r. p. 2*), is a very large nerve originating from the dorsal side of the posterior end of the parietal ganglion. It passes backward for a short distance, and terminates in a good sized ganglion, lying below the integument in front of the brachia. From this ganglion a nerve is sent to the ctenidium and the wall of the branchial chamber, another penetrates deeply among the muscles of the body wall, in front of the kidney and is probably distributed to the mantle, though its course could not be made out with certainty. The main portion of the ganglion supplies the osphradium, or organ of Spengel, a conspicuous oval elevation with a depressed center, situated just in front of and slightly above the base of the ctenidium.

THE REPRODUCTIVE SYSTEM.

The excellent work of Mazzarelli ('91) upon the reproductive apparatus of the Aplysiidae has cleared up many doubtful points in the structure and functions of this complicated system, though much remains still to be done. In the following discussion of this system in *Tethys dactylomela* I use the nomenclature adopted by him.

The reproductive system of the Aplysiidae is made up of the following structures, given in their order of occurrence from behind forward.

1. The ovotestis, or hermaphroditic gland.
2. The small hermaphroditic duct.
3. The adnexed genital mass, consisting of the nidamental and albumen glands, the fertilization chamber, and the convoluted and spiral portions of the genital duct.
4. The spermatocyst and duct of Cuvier.
5. The large hermaphroditic duct.
6. The spermatheca, or vesicle of Swammerdam.
7. The external spermatic groove.
8. The penis and its sheath.

The ovotestis forms the posterior end of the visceral mass, being more or less extensive depending upon the degree of sexual maturity of the individual. In the largest specimen at hand (140.0 mm. in total length) the ovotestis is large, flattened

ovoidal in shape, all its surface being convex, save the anterior one, which is irregularly concave to correspond with the surface of the posterior end of the liver and intestine, with which it is in close contact. Its surface is finely lobulate, light brown in color. From the antero-dorsal surface appears the light brown small hermaphroditic duct, very strongly convoluted in its course, 0.20 mm. in average diameter, its length being approximately 45.0 mm., though this could be estimated only, as it was impossible to straighten out its windings. Its distal end passes obliquely across the ventral side of the adnexed genital mass, thence recurving dorsally to enter the latter. The "adnexed genital mass" is a term applied by Robert ('89) to designate a complex made up principally of the nidamental and albumen glands and certain modifications of the genital duct. It is in the form of a dorso-ventrally flattened cone, situated obliquely to the longitudinal axis of the body. In the smaller specimens it was nearly flat, in the largest one quite large and more prismatic in form, its ventro-anterior surface flattened, the dorso-posterior one strongly arched. In length it varies from 2.0 mm. to 13.0 mm., and in width from 1.0 mm. to 10.0 mm. The texture of the largest one was very firm and somewhat brittle, the great increase in size being due to the activity of the nidamental and albumen glands. The small hermaphroditic duct, entering the anterior side of the basal portion of the mass, dilates into an irregular cavity, the fertilization chamber, into which open the duct of the albumen gland and the duct of Cuvier from the spermatocyst. Beyond this fertilization chamber the genital duct becomes very much convoluted for a short distance, passing thence over into the spiral portion, which largely constitutes by its windings the free portion of the mass, and incloses in its loops the greater portion of the albumen gland. Throughout the turns of this spiral one side of the duct is modified into the nidamental gland by a series of complicated foldings, the lumina of which communicate freely with the duct proper. Returning upon itself from the apex of the mass, the spiral portion widens out into the large hermaphroditic duct proper. By two longitudinal folds from opposite sides of this large hermaphroditic duct it is incompletely divided into two conduits. Owing to secondary twisting the relation at first existing of a right and a left portion

becomes modified in the course of the duct. At the proximal end the spiral portion of the genital duct is continued into the right half, while that on the left is prolonged into the duct of the spermatocyst and the duct of Cuvier, the latter communicating with the fertilization chamber. These relations may be more readily made out in an immature than in an adult specimen, and best of all, in serial sections. The spermatocyst is a pear shaped sack, doubled upon itself, situated at the anterior margin of the base of the adnexed genital mass, from which it projects freely for the greater portion of its length. It is ca. 4.9 mm. long and 2.3 mm. in maximum diameter in the largest specimen examined, but much smaller in the others.

The large hermaphroditic duct extends from the adnexed genital mass to the vulvar opening, with a length of 17.9 mm. and a diameter of 0.5 mm. in the largest individual. It is externally marked to correspond to its internal differentiation into two ducts, the one on the right the ovo-spermatic, that on the left the copulatory duct. The latter duct, beyond the entrance of the duct of the spermatocyst, becomes the vagina. The outer surface of the right of these ducts is of a yellowish brown color and transversely rugose. The surface of the left half is smooth and dark brown. At a distance from the vulvar opening of about one-fifth the whole length of the large hermaphroditic duct, the duct of the spermatheca, or vesicle of Swammerdam opens into the left or copulatory duct. The vesicle itself is a large, spherical structure, 5.0 mm. in maximum diameter, lying immediately to the left of the parieto-visceral ganglion. By a slender duct, 0.9 mm. in diameter and 6.2 mm. in length, in the largest specimen, it communicates with the copulatory duct.

The right half of the large hermaphroditic duct, which functions alike as oviduct and vas deferens, the ovo-spermatic duct, the "ovidutto-deferente" of Mazzarelli, is continued forward as a narrow external groove along the right side of the animal from the genital opening to the right side of the head, close below the right anterior tentacle. In the largest specimen the external spermatic groove measured 85.00 mm. in length. Here it is continued inward along the inner wall of the penis sheath to its base, whence it recurves along the side of the penis to its tip, thus forming a conduit for the spermatozoa in copulation.

The penis sheath has moderately thick, muscular walls, is nearly cylindrical, slightly tapering in the retracted condition. The diameter of its proximal end is 2.0 mm. the total length 11.5 mm. in an individual of 70.0 mm. total length. To its proximal end are attached two strong retractor muscles, a dorsal and a ventral one. Along the outer dorsal side of the lumen the spermatic groove is continued as a deep depression, the margins of which are elevated into prominent ridges, and more or less sprinkled with brown pigment, which in some case is aggregated into continuous narrow longitudinal lines. At the basal end of the penis sack this groove is reflected forward upon the surface of the penis along its full length to the tip. The penis is a flattened muscular organ, tapering distally to a blunt point. In the specimen of 70.0 mm. total body length, it measured 1.9 mm. in maximum basal diameter, with a total length of 7.5 mm., though the presence of numerous transverse folds in the basal portion indicated that this was not the full normal length. No trace of pigmentation is evident, nor is there any specialized armature developed. The external groove is ciliated throughout its whole extent.

THE ORGAN OF BOHADSCH.

The organ of Bohadsch, or hypobranchial gland, (Pl. III, fig. 17), is a large yellowish white structure, irregularly spherical in form, and 15.5 mm. in diameter in the largest specimen. Its surface has the characteristic nodular appearance due to the very large cells of which it is composed. In the largest specimen the texture of the gland was for the most part quite firm, in the smaller ones very soft, a difference apparently due to the large amount of secretion present in the former. The single duct is short and broad, the large, external opening conspicuously located below and slightly behind the anterior margin of the base of the ctenidium.

EXCRETORY AND CIRCULATORY SYSTEMS.

The relations of the kidney and the pericardium are substantially the same as described by Cunningham ('83) for the Mediterranean species, and will not be taken up in detail.

Leland Stanford Junior University Zoological Museum,
Invertebrate Series No. 143.

***Tethys cervina* Dall and Simpson.**

Plates. III-VIII, Figs. 15-35; Plates IX-X, Figs. 39-42.

Tethys cervina Dall and Simpson, The Mollusca of Porto Rico.
Bulletin U. S. Fish Commission, XX, 1900, Part I.
(Issued Nov. 29, 1901). p. 365, Pl. 56, fig. 2.

One specimen of a *Tethys* different from the foregoing, labeled "Sand Beach, Maceio, Alagoas. July 31, 1899. A. W. Greeley col." was found in the collection, no other notes accompanying it. In my opinion it is identical with the *Tethys cervina* of Dall and Simpson taken at Mayaguez, Porto Rico, and described in the publication cited above. The description of Dall and Simpson is as follows:

"Body elongated, flabby; mouth encircled by thick lips; tentacles short; eyes inserted in front of the tentacles. Swimming lobes thick, united behind at some distance in front of the hinder extremity; mantle orifice minute; mantle ending behind in a small fold; foot narrow, nearly smooth.

"Colors: The body is a lurid gray, overlaid with reticulations and blotches of darker color. It also has scattered, small, nearly round, smoky brown spots throughout its surface. The foot is smoky brown, lighter color than the spots. The inner edges of the swimming lobes are beautifully and distinctly maculate, with alternating light and dark patches. The mantle is colored like the body, but the dark spots are wanting, and the dark reticulations are somewhat radiating. Length 7 cm.

"Shell with a rather strong layer of lime, elliptical in outline; posterior sinus moderate. Length of shell 30; breadth 19 mm.

"Mayaguez, Porto Rico."

The following points are based upon the Brazil specimen, and will serve as supplementary to the description of the former authors in anatomical details.

EXTERNAL CHARACTERS.

Body form. The body (Pl. X, fig. 41), is soft, plump and smooth, the head and caudal regions being rather contracted, the remainder of the body but little distorted. The total length of the specimen is 40 mm., its width and height being 20 mm.

Color. The general color is a pale yellowish gray, sprinkled above and on the sides with minute dark brown spots. The dorsal surface of the mantle, covering the shell, is pale grayish, with fine slightly elongate markings of dark brown arranged in inconspicuous radiate lines around the minute opening into the shell cavity. These radiate bands of dark color branch irregularly above the periphery of the shell and merge into the general mottling of the body. The sides of the body are marked with a few (eight to ten), irregularly scattered, larger, dark brown flecks, the largest of which is not over 1.0 mm. in diameter. The inner surface of the parapodial lobes is marked with irregular dark brown maculations, alternating with lighter areas. The foot is light brown throughout. These notes were all made from the specimens while in formalin. On being transferred to alcohol, the darker colors gradually became much paler and disappeared more or less completely throughout.

Foot. The foot is very narrow, being strongly contracted, especially midway of its length, there being reduced to 2.0 mm. in width, but broadening in front to 7.0 mm., and behind to 4.0 mm., terminating in a short, bluntly pointed tail. The anterior end of the foot is broad and blunt with rounded outer angles.

Parapodia. The parapodial lobes are 29 mm. in length, occupying nearly three-fourths of the entire length of the animal. They are rather low and not at all prominent, being but 10.0 mm. in extreme height. The lobes are fleshy, their margins thin and slightly undulating, being slightly rugose locally, a condition probably due to contraction. The anterior ends of the lobes are widely separated, the interval being 6.5 mm., which is lessened at the posterior end to 0.5 mm. though the lobes are distinct and not completely joined behind the siphon.

Mantle. The mantle area is distended and plump, the minute central opening into the shell cavity is borne upon a low papilla, which is rendered more conspicuous by the radiate pigmentation above described. On the right side the mantle extends in a thin-edged semitranslucent flap over the gill cavity. Posteriorly its right margin is deeply notched, the edges being elevated and rolled together, forming the prominent excurrent siphon, which extends backward and upward between the edges of the parapodia to a height of 3.0 mm.

***Tethys cervina* Dall and Simpson.**

Plates. III-VIII, Figs. 15-35; Plates IX-X, Figs. 39-42.

Tethys cervina Dall and Simpson, The Mollusca of Porto Rico. Bulletin U. S. Fish Commission, XX, 1900, Part I. (Issued Nov. 29, 1901). p. 365, Pl. 56, fig. 2.

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"Mayaguez, Porto Rico."

The following points are based upon the Brazil specimen, and will serve as supplementary to the description of the former authors in anatomical details.

EXTERNAL CHARACTERS.

Body form. The body (Pl. X, fig. 41), is soft, plump and smooth, the head and caudal regions being rather contracted, the remainder of the body but little distorted. The total length of the specimen is 40 mm., its width and height being 20 mm.

face. They are composed of the usual rolled plate with an external, auriform slit. The bases are wide apart being separated by 3.0 mm. distance.

INTERNAL ANATOMY.

The animal was opened along the median line of the foot by a longitudinal incision, in order to disturb the viscera as little as possible. The peritoneum is colorless, the liver light chocolate, the grey windings of the intestine inclosing it in spiral turns.

ALIMENTARY SYSTEM.

Pharyngeal bulb. The pharyngeal bulb is nearly spherical and slightly elongate, the radula sack projecting from its ventral surface as a prominent, rounded eminence. The salivary glands are long, slender and strap shaped, their relations being similar to *Tethys dactylomela* and other *Aplysiidae*. A pair of oblong lateral laminae, placed obliquely, the mandibular plates, (Pl. III, fig. 15), guard the entrance of the pharyngeal bulb, being separated above and below by a narrow interval. The extreme width of a mandible is approximately two-thirds of its greatest length, the actual measurements in the individual at hand being 3.00 mm. in length by 1.9 mm. in width. The borders of the mandibles are rounded. Each lamina is made up of a countless number of flexible, nearly straight rodlets with slightly dilated blunt tips (Pl. III, fig. 16), having a maximum length of 0.09 mm. and a diameter of 0.006 mm., the length decreasing toward the posterior border of the lamina, the diameter remaining the same, the rodlet being somewhat flattened antero-posteriorly. The bases of the rodlets are supported by a homogenous horny cuticula of considerable thickness.

Radula. The radula is of a deep amber color in its anterior older portion, becoming much lighter posteriorly. It measures 5.0 mm. in greatest length by 4.8 mm. in width at its posterior end, tapering, at first gradually, then more rapidly for the last two-fifths of its length to a rounded anterior end. The anterior rows of teeth are incomplete, being worn away and broken by use. The teeth are arranged in 38 rows, the last 15 of which are inclosed in the radula sheath. The number of teeth in each

row increases from 16:1:16 in the oldest complete row to 22:1:22 in the thirtieth. The dental formula of this individual may be expressed then as 38x16-22:1:16-22. The rhachis bears a single, massive tooth (Pl. IV, fig. 23; Pl. V, fig. 26, *m*), its base, trapezoidal in form, measuring 0.27 mm. in width at its posterior end and 0.132 mm. in length, varying but slightly from these dimensions throughout the length of the radula. The posterior margin is slightly emarginate, the anterior one deeply so, the curve being carried up on the anterior face of the hook as a broad, deep groove. The anterior end is prolonged upward and backward in a strong hook, terminating in a stout, triangular, median cusp, upon either side of which are borne two smaller cusps typically. The larger of these, next to the median one, is from one-half to two-thirds the length of the latter; the outer ones are very much smaller and are more variable in both form and size.

With the exception of the outermost three to five teeth, the lateral teeth are strongly hooked and of similar form, decreasing gradually in size toward the outer borders of the radula (Pl. IV, figs. 23-25). Each lateral tooth (Pl. IV, figs. 23-25; Pl. V, figs. 26-30), consists of a stout oblong base obliquely placed, from the dilated anterior end of which arises a stout hook, terminating in a triangular cusp. The sides of this cusp bear four to ten denticles, quite small near the tip and, in general, increasing in size toward the base, though irregularities in this are not infrequent. Upon the inner side of each tooth, at the base of the hook, the series of denticles is terminated usually by a very large and broad denticle, while upon the outer flank of the main cusp a series of two or three smaller cusps is borne. In the radula of *Tethys dactylomela* there is but one external cusp in this position, which is usually itself denticulate, but in *T. cervina* the margins are uniformly smooth (cf. Pl. I, figs. 1-5, and Pl. IV and V, figs. 23-30). Indications of a fourth lateral cusp at the extreme end of this series are frequently found. The first ten laterals are approximately equal in size (Pl. IV, figs. 23-24, 1-10), the remaining ones decrease toward the outer border of the radula (Pl. IV, fig. 25), the hook finally becomes rudimentary and disappears altogether, the outermost three to five teeth being reduced to oblong flattened plates (Pl. V, fig. 28). The teeth of this species

are in general about two-thirds the size of those of *Tethys dactylomela*.

The visceral mass nearly fills the body cavity of the animal. It is made up of the esophagus, the three divisions of the stomach, and the intestine, the latter inclosing in its windings the liver and the ovotestis.

Esophagus and stomach. The esophagus is short and rather thin walled, dilating into the very ample first stomach, or ingluvies (Pl. VI, fig. 31, *ingl.*), a thin walled sack, densely packed with fragments of algae. The whole alimentary canal is spirally twisted from left to right, clockwise. The ingluvies occupies about one turn of this spiral, the second, or grinding stomach (Pl. VI, fig. 31, *m. st.*), together with the third gastric division completing about one-half of the second turn. The anterior end of the ingluvies dilates rather suddenly from the esophageal tube, the posterior end tapering more gently to the broad band like circular constriction in the canal, marking externally the limits of the thick walled, muscular, second, or grinding stomach (Pl. VI, fig. 31, *m. st.*). This portion is about 4.0 mm. in length by 5.0 mm. in diameter at its anterior end, tapering somewhat posteriorly. Its inner surface bears a number of strong horny teeth, arranged in five somewhat irregular rows, the anterior ones of which contain the smaller teeth, the succeeding ones increasingly larger, and the last two the largest. The tips of this gastric armature meet in the center of the lumen in the contracted condition, thus making a most effective gastric mill. In general the form of these teeth is the same throughout, being that of a four sided pyramid, the base a rhomb in outline with one of the acute angles directed forward. In the largest teeth of the posterior rows (Pl. III, fig. 21), the crest is either single, rounded and bluntly pointed, or wedge shaped, being prolonged into a transverse ridge. In most cases this ridge shows three distinct summits, separated from each other by shallow depressions, which are continued downward upon the anterior face in two deep grooves, while the posterior face is more uniformly convex. The base frequently presents a transverse median depression upon its ventral surface, corresponding in position to the region of greatest elevation above (Pl. III, fig. 21). The smaller teeth, found in the two anterior rows, have a single groove upon the anterior face, carried up to

the cusp, which is single, and may present the form of a point (Pl. III, figs. 18, 19), or of a transverse wall with a concave front face (Pl. III, fig. 20). At the anterior margin of each of these smaller teeth rises a lower median cusp, which is connected by a lower sloping ridge with the posterior higher main one (Pl. III, figs. 18, 19). All these teeth are borne upon thickened disks of epithelium with elevated margins and concave central portions, corresponding to the convex bases of the teeth.

The third stomach (Pl. VI, fig. 31, 3 *st.*), is nearly as thin walled as the first one, and is about one-fourth as long, being 6.0 mm. in length upon its greater curvature. It increases in diameter from the posterior border of the second stomach for a short distance, then tapers as it becomes imbedded in the posterior visceral mass. The inner wall of the third stomach bears a circular band of small flattened horny teeth, approaching close to the anterior margin of the stomach on the side of the lesser curvature, and arching backward from this region around the greater curvature, there reaching a distance of 4.0 mm. from the anterior margin. The tooth bearing zone is 2.0 mm. in width throughout its whole extent. The teeth are much more highly developed than in *Tethys dactylomela*, are curved and conical in shape (Pl. III, fig. 22), and are much more irregularly arranged than in the second stomach, small and large teeth being intermingled. Behind this tooth bearing zone a few small and slender teeth of similar shape are irregularly scattered.

Intestine. The intestine is twisted in a slightly more complicated way than the gastric region just described, the greater part describing a wide loop upon the left side and upper surface, the terminal portion then returning to the simple spiral form (Pl. VI, fig. 31, *int.*). Within the coils of the intestine are inclosed the liver and the ovotestis, the outer surface of the former showing throughout its whole extent, though so deeply imbedded in the liver as to everywhere present a smooth surface. It is a simple, thin-walled tube save at the most anterior portion, where it is dilated somewhat, and receives a slender diverticulum, the "hepatic coecum" of Mazzarelli and Zuccardi (Pl. VI, fig. 31 *h. cæ.*). Upon opening the intestine at its anterior end a large cavity in the substance of the liver is disclosed (Pl. VI, fig. 32), into which open three large principal ducts and several smaller

ones, which ramify throughout the liver, conveying its secretion to the central biliary cavity. Into the posterior side of this chamber opens the hepatic coecum (Pl. VI, fig. 32, *h. cæ.*), a narrow curved cylindrical tube, at first imbedded in the liver, but appearing at its surface for the distal third of its length. It is 9.0 mm. in length, the diameter varying from 1.0 mm. to 1.25 mm. It is traversed by two longitudinal folds, arising from opposite sides, the one higher than the other, which meet and overlap, thus dividing the lumen into two practically separate, longitudinal portions, united at the blind, distal end. At the opening of the coecum into the bile chamber, the anterior one of these communicates freely with the latter, its walls being grooved and folded in prolongation of similar folds and grooves in the wall of the bile chamber. The posterior half of the coecum communicates as a deep groove with the intestine, one of the median, longitudinal folds in the wall of the coecum being continued across the opening of the bile chamber and down into the intestine (Pl. VI, fig. 32, *l. r.*), there gradually merging with its wall.

THE CENTRAL NERVOUS SYSTEM.

The central nervous system (Pl. VII, fig. 34) is made up of three pairs of ganglia resting upon the posterior end of the pharyngeal bulb, and, with their commissures, encircling the commencement of the esophagus. These are the cerebral, the pedal and the pleural ganglia, each pair united by commissures of varying length, while the ganglia of each side are united in a triangular grouping by the cerebro-pedal, the cerebro-pleural, and the pleuro-pedal connectives. Close to these ganglia, and to be included with them in the central nervous system, are the buccal ganglia, situated on the ventral side of the esophagus, and forming with their cerebral connections, the cerebro-buccal connectives, another ring around the anterior end of the alimentary canal. These structures will be taken up briefly in the following description. On plate VII is figured a dorsal view of the whole central nervous system of *Tethys cervina*, excepting the buccal ganglia, together with the origins of the nerves taken up in the following pages. As in the similar figure of the preceding species of *Tethys*, given on Plate II, the nerves are numbered in the

order of their appearance from in front and above downward and backward. All abbreviations in the following description refer to fig. 34, Plate VII, unless otherwise indicated.

Cerebral ganglia. The cerebral (*cer. g.*) ganglia are completely fused together into a large quadrilateral mass, all traces of their primitive separation into right and left moities having disappeared. The nodulated dorsal surface of the mass is highly arched, the ventral slightly concave. In width the complex measured 1.5 mm., in length 0.9 mm. and in thickness 0.7 mm. A slender, sub-esophageal, cerebral commissure passes below the esophagus, connecting the halves of the ganglionic mass together ventrally. In fig. 34, Pl. VII, *s. c. com.*, it is seen inclosed in the same sheath of connective tissue as the pedal commissure and lying at its anterior margin.

Cerebral nerves. From the cerebral ganglia arise six pairs of nerves and three connectives, the origins of which are the same for each side.

The first cerebral nerve (*c. 1*) arises from the anterior outer face of the ganglion, and courses forward to its distribution to the skin and the muscles of the mouth region.

The second cerebral nerve (*c. 2*) arises immediately behind the first, and is much larger. It curves forward along the pharyngeal bulb, giving off, midway of its length, a strong outer branch to the anterior tentacle, in which it terminates in a small ganglion. The main trunk breaks up into a number of divisions, which are distributed to the muscles and integument of the mouth region.

The third cerebral nerve (*c. 3*) arises from the upper dorsal border of the ganglion, and is distributed mainly to the rhinophore, in which it terminates in a small ganglion. It also gives off two or three slender branches, the first and largest of which forms, apparently, an anastomosis with the optic nerve. It is not a true fusion, however, the two nerves being merely united in a common, epineural sheath for a short distance. The distribution of this and the other slender branches of the third nerve is to the integument in the neighborhood of the eye and rhinophore. Upon the right side a true anastomosis occurs with a branch of the second pedal nerve, as shown at *x*. in the figure and to be described further on.

The fourth, or optic nerve (*c. 4*) is slender, long and unbranched. It arises from the dorsal margin of the ganglion and passes outward and upward to the eye. No special optic ganglion can be made out at its base without serial sections.

The fifth cerebral nerve (*c. 5*) arises from the postero-lateral face of the ganglion, immediately above the origin of the cerebro-buccal connectives. It is a rather slender nerve, passing forward and ramifying to the muscles of the mouth region. That of the right side sends, in addition, a branch to the penis.

The sixth cerebral, or auditory nerve, is closely associated with the cerebro-pedal connectives and is not visible in dorsal view. It arises close to the base of the connective, and follows it to the upper face of the pedal ganglion where it terminates in the otocyst, being throughout its course inclosed in the connective tissue sheath of the cerebro-pedal connective (*c. p. con.*).

Three sets of connectives arise from the cerebral ganglia, the cerebro-buccal, the cerebro-pleural and the cerebro-pedal. The first named pair is the longest, arising from the outer ventral margins of the ganglia, and encircling the anterior end of the esophagus to unite with the buccal ganglia beneath. They are not visible in fig. 34. The cerebro-pedal connectives (*c. p. con.*), pass obliquely outward and backward from their origins upon the postero-ventral margin of the cerebral ganglia to the pedal ganglia (*ped. g.*). They are short and thick, and are inclosed in a strong connective tissue sheath with the cerebro-pleural connectives (*c. pl. con.*), which are of nearly equal diameter, but less long.

Pedal ganglia. The pedal ganglia (*ped. g.*), are rounded flattened structures, measuring 1.4 mm. in diameter and 0.6 mm. in maximum thickness. They are connected below the esophagus by a strong commissure (*p. com.*), 1.0 mm. long and 0.15 mm. wide. A much longer and quite slender parapedal commissure (*p. p. com.*), arising from the lower posterior margin of each ganglion also unites the two. Upon the upper margin of the pedal ganglia are received the cerebro-pedal connectives and just behind them the very short pleuro-pedal ones. From each ganglion ten nerves are given off. These will be described for the right side, any difference which may exist upon the opposite one being noted. The nerves are taken in order and numbered in the

series from the upper anterior margin of the ganglion, downward and backward. For the nerves originating along the outer margin of the ganglion this presents no difficulties, but those nerves which arise from the median portion of the ventro-anterior face are of necessity more arbitrarily assigned their position in the series as indicated.

Pedal nerves. The first nerve (1), is a very slender one, arising from the upper ventro-anterior face of the pedal ganglion, just below and external to the entrance of the cerebro-pedal connective, and very close to the origin of the second nerve. It passes outward and forward to the integument in the eye region.

The second nerve (2), is similar in size to the first nerve, arises quite close to it, and in some specimens may possibly be found to branch from a common trunk with it. It courses outward and upward, dividing into two branches near the proximal end of the penis. The dorsal one of these branches passes to the dorsal retractor of the penis sheath, the ventral subdivision gives off a twig which anastomoses with a branch of the third cerebral nerve, another to the ventral retractor of the penis sheath, and then courses forward below the penis to its distal end, giving off several minute branches to it. The extreme ramifications of this portion of the nerve are to the anterior end of the penis sheath and to the muscles and integument surrounding it. Upon the left side this nerve is distributed to the muscles and integument of the body wall from the eye forward.

In *Tethys dactylomela* these two nerves, numbers one and two of *T. cervina*, are represented by but one nerve, described as the first on page 27, and so figured in Pl. II, *p. 1*, but with the same distribution as the first and second here described.

The third pedal nerve (3) arises from the upper external margin of the ganglion and bifurcates almost immediately. The anterior one of these branches divides in turn almost at once, one branch, 3*a*, forming an anastomosis with the first pleural nerve (*pl. 1*), being like it distributed to the dorsal peritoneum and musculature back to the heart region, the other, 3*b*, passing directly backward to a similar distribution. The posterior main branch (3*c*) is much longer and is shown in detail in fig. 35 of Pl. VIII. It curves backward, sends off a branch (fig. 35, 3*b*), to the right lateral retractor muscle of the head, and to the body wall

above it, another (fig. 35, 3c), to the Organ of Bohadsch, or hypobranchial gland, and finally (fig. 35, 3f), unites with the first nerve from the right parietal ganglion, thus forming a parieto-pedal connective. From the above mentioned branch (fig. 35, 3b), to the lateral retractor of the head a branch is given off which courses backward along the body wall, passes beneath the right margin of the Organ of Bohadsch, and well beyond the latter forms an anastomosis at an acute angle with the recurrent branch (fig. 35, 2c) of the second nerve (fig. 35, l. v. 2), of the *left* visceral ganglion, which also sends a branch to the Organ of Bohadsch, as will be described below. In *Tethys dactylomela* the third pedal nerve is represented by two separate nerves, the second and third of the description on page 28, they corresponding in their distribution to the third nerve alone of *T. cervina*.

The fourth pedal nerve (4) is long and slender, arising from the outer margin of the ganglion and passing backward to the parapodium of the same side.

The fifth pedal nerve (5) is a strong one from the median lateral margin of the ganglion. Close to its origin it gives off a slender branch (5a) which might possibly be considered a separate nerve, though its distribution is the same as that of the main nerve, to the parapodium. In *T. dactylomela* a similar branch is given off from the fifth nerve, but its origin is further removed from the base of that nerve. Its distribution is the same as that here indicated.

The sixth, or posterior pedal nerve (6) is the longest of the nerves from the pedal ganglion. It arises from the mid-lateral margin of the ganglion, curves backward, unbranched for over one-half of its course, and is distributed to the posterior portion of the foot.

The seventh pedal nerve (7) arises upon the lower portion of the ventro-anterior face of the ganglion, below the origin of the first and second nerves. Like these and the ninth is closely imbedded in the connective tissue surrounding the pharyngeal bulb and may be dissected out with some difficulty. A branch of the seventh forms an anastomosis with the ninth, and both are distributed to the muscles and integument of the side of the head. The nerves of both sides are alike in origin and distribution.

The eighth, or median pedal nerve (8) is a strong trunk

arising from the outer lower margin of the ganglion and is distributed to the middle region of the foot. Upon the left side its origin is slightly more removed from that of the tenth.

The ninth pedal nerve (9) arises from the ventral portion of the lower anterior face of the ganglion. It is quite slender and forms an anastomosis with a branch of the seventh. Its distribution has been given above in connection with that of the latter nerve, and is similar on both sides.

The tenth, or anterior pedal nerve (10), is a large trunk from the outer lower margin of the ganglion. It doubles forward in four main divisions beneath the pharyngeal bulb and is distributed to the anterior portion of the foot.

The order, arrangement and distribution of the pedal nerves is the same for the two species of *Tethys* here studied, but they disagree markedly with the accounts given by other authors, notably Von Ihering ('77) and Mazzarelli ('93), for the Mediterranean forms. Until I am able to secure material for a detailed comparison of all the species concerned I cannot explain this lack of agreement. Von Ihering ('77) describes and figures but six nerves from each ganglion. Mazzarelli ('93) describes and figures seven paired pedal nerves and one unpaired one upon the right side, and two unpaired ones upon the left, their order and distribution not agreeing with the Brazilian forms, while Lacaze-Duthiers ('87) found but six in all.

Pleural ganglia. The pleural ganglia (*pl. g.*), are situated just above, and in contact with the upper surface of the pedal ganglia, with which they are connected by the very short pleuro-pedal connectives. They are about one-third the size of the pedal ganglia, and are spheroidal in outline, measuring 0.5 mm. in greatest diameter. They are made up of large conspicuous cells, which give their surface a knobbed appearance. Contrary to the descriptions and figures of Von Ihering ('77), and Mazzarelli ('93), I find that the pleural ganglia give rise to the following nerves.

Pleural nerves. From the left pleural ganglion arise two nerves. The first (*pl. 1*), is a slender nerve from the superior face of the ganglion. It passes outward and downward, receives an anastomosing branch from the third pedal nerve and ramifies

to the peritoneum and the muscles of the dorsal body wall, just above and behind the region of the central nervous system.

The second pleural nerve (*pl. 2*), arises just exterior to the origin of the pleuro-visceral connective. It passes backward as a long slender unbranched trunk in the dorsal peritoneum, to the region of the pericardium, in the anterior wall of which it ramifies among the muscles.

From the right pleural ganglion but one nerve (*pl. 1*), is given off. It corresponds to the first one of the left side and has a similar distribution. It also receives an anastomosing branch, 3a, from the third pedal nerve of the right side.

From the median posterior face of the ganglia arise the long and strong connectives, which pass backward to the ganglion complex upon the visceral loop, situated immediately below the anterior boundary of the pericardium. The left of these connectives (*pl. v. con.*), is slightly longer than its fellow, measuring 14.0 mm., as compared with 12.0 mm. for that of the right side. The right of these (*pl. par. con.*), is the pleuro-parietal connective, the left the pleuro-visceral one. Their peripheral relations will be taken up further on.

Buccal ganglia. The buccal ganglia are oval in outline, each measuring 0.45 mm. in length by 0.42 mm. in width, and are connected by a broad commissure 0.18 mm. in length, so that the two ganglia are distinctly separated from each other, though enveloped in a common connective tissue sheath. From the anterior median face is given off a strong unpaired nerve as in *Tethys dactylomela*, soon bifurcating to the muscles of the rotella. From the outer side of each ganglion four nerves are given off, in addition to the cerebro-buccal commissures. These nerves are distributed to the pharyngeal bulb, the salivary glands and the esophagus, but their ramifications were not worked out in detail.

Parieto-visceral ganglia. The parieto-visceral ganglion group (Pl. VIII, fig. 35, *par. v. g.*), is situated beneath the dorsal wall of the body, slightly to the right of the median line and directly below the anterior border of the pericardium. The composition of the group as made up of a right and left portion, fused in the median plane, can be readily made out, but any further division into component ganglia is not indicated in surface view. The double nature of the group is marked only at the

anterior end by the entrance of the respective connectives, and by a slight groove upon the anterior face. The nerve cells of these ganglia are of the usual gigantic type found in Opisthobranchs generally, and cause the surface of the ganglia to present a series of irregular protuberances.

Parietal nerves. From the right or parietal ganglion arise two nerves.

1. The vulvar nerve (Pl. VIII, fig. 35; Pl. X, fig. 42, *r. p. 1*), is a delicate trunk from the right side, soon bifurcating into (a), a branch (figs. 35, 42, *r. p. 1a*) coursing forward and anastomosing with a branch of the third pedal nerve (Pl. VIII, fig. 35, *3f*), forming the pedo-parietal connective before described, and (b), the vulvar nerve proper (Pl. VIII, fig. 35; Pl. X, fig. 42, *r. p. 1b*), which passes to the anterior end of the large hermaphroditic duct and to the integument surrounding it.

2. The second, or osphradio-ctenidial nerve (Pl. VIII, fig. 35; Pl. X, fig. 42, *r. p. 2*), is a very strong trunk, in diameter quite reaching that of the pleuro-parietal connective. It arises from the upper right side of the parietal ganglion, passes outward and backward in a curve to the right, thence upward to the anterior base of the ctenidium, where it unites with the large ganglion of the osphradium (Pl. VIII, fig. 35; Pl. X, fig. 42, *osp. g.*), lying immediately below the integument, and visible through it. The osphradium is visible externally as a depressed oval area of a light yellowish color, situated upon the ventral face of the anterior portion of the base of the ctenidium. It is 0.4 mm. in length by 0.1 mm. in width. From this osphradial ganglion arise two rather strong nerves, one (Pl. VIII, fig. 35; Pl. X, fig. 42, *osp. g. 1*), passing forward, its several branches being distributed among the large gland cells of the anterior and lateral margins of the mantle. The other nerve from the osphradial ganglion passes a short distance to the left and terminates in a smaller branchial ganglion (Pl. X, fig. 42, *ct. g.*) at the right of the pericardium. From this ganglion a main branchial nerve (Pl. X, fig. 42, *ct. n.*), passes backward to the ctenidium, and several very delicate nerves are also given off to the pericardial wall and are lost among its fibres.

Visceral nerves. The left, or visceral ganglion is equal in size to the right parietal one. At its anterior, more pointed end it

receives the distal end of the left pleuro-visceral connective. From its posterior portion it gives origin to the following four nerves.

1. From near the posterior median line arises a slender nerve (Pl. X, fig. 42, *l. v. 1*), which immediately bifurcates to the Vesicle of Swammerdam, or spermatheca, and its duct, a slender branch being also continued to the adjacent peritoneum.

2. A large nerve (Pl. VIII, fig. 35, *l. v. 2*), given off from the posterior right side of the ganglion, passes obliquely backward to the right, crossing the large hermaphroditic duct midway of its length, to the posterior end of the body. It gives off a number of slender branches to the dorsal peritoneum, and a larger one, *2a*, to the liver, separating from the main nerve near its origin, but continued with it in a common epineural sheath for some distance. A little beyond the middle of its course the second nerve gives off a moderately strong recurrent branch to the right, *2c*, and then passes straight backward, *2b*, bifurcating to the anal portion of the intestine, and to the siphon. From the recurrent nerve, *2c*, a long, posterior branch, *2d*, is given off, which is distributed to the peritoneum in the median posterior region near the rectum; the main nerve, curving forward, sends one or two very delicate branches to the peritoneum, a stronger one, *2e*, to the posterior face of the Organ of Bohadsch, passes beneath the right margin of the latter gland, and forms an anastomosis with the terminal branch of the third pedal nerve, *3e*, which, it will be remembered, sends a branch to the anterior face of the Organ of Bohadsch, and one uniting with the vulvar nerve from the right parietal ganglion. By this arrangement the hypobranchial gland receives its nerve supply not only from the right pedal ganglion, but also from the left visceral one as well. It would be an interesting physiological problem to determine the relative influence of these two nerves with such different origins upon the secretory activity of the gland. Mazzarelli ('90) has made a comparative study of the morphology of the gland of Bohadsch in a number of Aplysiidae, and has represented diagrammatically the innervation in seven species. In all of these the nerve supply is found to be from the right pedal ganglion, but in none of them is any mention made of such relations as are here described for the two Brazilian species. In figs. 36 and 37 of Plate IX I have reproduced Mazzarelli's figures 17 and 19 of Tav. I for *Tethys punctata*

and *Tethys depilans* as typical of his results. In figs. 38 and 39 of the same plate I have made similar diagrams showing the innervation for *Tethys dactylomela* and *Tethys cervina*, according to my dissections. Vayssi re ('85) describes and figures for *Tethys depilans* a branch of the "nerf genital," which originates from the left visceral ganglion (not from the right, as quoted by Mazzarelli, p. 8), and passes to the "glande opaline," or gland of Bohadsch, as in the forms here described. He does not find, however, the innervation from the pedal ganglion also. Mazzarelli disputes the accuracy of the observations of Vayssi re, holding that the nerve supply is from the pedal ganglion alone. In *Tethys dactylomela* and *Tethys cervina* we have seen that both ganglia in question send nerves to the Organ of Bohadsch, so in these forms both authors would be partly right, and it would not be a matter of great surprise to find, upon a reexamination of the Mediterranean Aplysiidae that in them also the double innervation actually exists.

3. The third nerve (Pl. VIII, fig. 35; Pl. X, fig. 42, *l. v. 3*), arises from the posterior margin of the left visceral ganglion and courses backward, giving off a slender branch to the liver, crosses the large hermaphroditic duct near its origin, sending a delicate branch to it, swells into the small genital ganglion, (Pl. VIII, fig. 35, *g. g.*), lying at the base of the adnexed genital mass, and thence passes backward parallel to the small hermaphroditic duct for nearly one-half the length of the latter. To this duct it sends a branch (Pl. VIII, fig. 35, *v. 3a*), which passes backward along its surface to the ovotestis, sending a few delicate branches to the duct on the way. The main trunk (Pl. VIII, fig. 35, *v. 3b*), turns abruptly to the right, leaving the hermaphroditic duct and, passing backward, ramifies in the dorsal body wall in front of the anal portion of the alimentary canal.

4. The fourth nerve (Pl. VIII, fig. 35; Pl. X, fig. 42, *l. v. 4*), equal in size to the second and third, arises at the posterior end of the ganglion, close to the base of the third nerve, diverges to the left, sending a branch to the liver, and courses obliquely across below the pericardium to its posterior wall. A strong branch (Pl. VIII, fig. 35, *4a*), is sent off about midway of this course which ramifies to the ventricle and the pericardial wall, the main trunk, (Pl. VIII, fig. 35, *4b*), curving dorsally in the posterior

wall of the pericardium, bifurcates to the kidney, the dorsal pericardial wall and the auricle near the entrance of the branchial vein.

In *Tethys dactylomela* and in the Mediterranean Aplysiidae studied by Mazzarelli ('93, Monog. p. 108) the third and fourth nerves, here described as separate for *Tethys cervina*, are united in one trunk for some distance from their origin.

THE REPRODUCTIVE SYSTEM.

The ovotestis (Pl. VI, fig. 33, *ov. t.*) is an irregular lobulate organ, situated at the posterior end of the visceral mass, closely united to the liver in front, and inclosed in the last turns of the intestine. From its median antero-dorsal face the small hermaphroditic duct (Pl. VI, fig. 33, *sm. h. d.*) arises, a white nearly straight tube, 9.0 mm. in length, gradually increasing in diameter from 0.3 mm. as it emerges from the ovotestis, to 0.8 mm. near the adnexed genital mass. The adnexed genital mass is a flattened, elliptical complex, made up of the nidamental and albumen glands and the fertilization chamber, inclosed in the loops of the genital duct, (fig. 33, *sp. p., c. p.*), and is situated immediately behind and below the right posterior border of the pericardium. It is 2.0 mm. in length, 1.3 mm. in greatest width, and 1.0 mm. in thickness. Its position is in almost direct prolongation of the large hermaphroditic duct, which extends forward along the right body wall to the external opening. At the left of its basal end the spermatocyst (Pl. VI, fig. 33, *sp. c.*) projects transversely as a free pear-shaped sack, its length, 1.0 mm., being one-half the length of the adnexed genital mass, while its diameter is nearly 0.5 mm. Its duct (Pl. VI, fig. 33, *d. C.*), the "duct of Cuvier," opens into the proximal end of the copulatory duct (Pl. VI, fig. 33, *cop. d.*). The stout large hermaphroditic duct is 4.5 mm. in length, one-half that of the small hermaphroditic duct, its diameter 1.0 mm. being practically the same throughout. It is made up of two channels, separated by deep folds of the dorsal and ventral walls, which overlap in the median line thus forming the ovo-spermatic duct (Pl. VI, fig. 33, *ov. sp. d.*) and the copulatory duct (Pl. VI, fig. 33, *cop. d.*). At its distal end it is slightly enlarged and receives the long slender duct of the vesicle of Swammerdam, the spermatheca, (Pl. VI, fig. 33, *spth.*), which enters from the left side and above. This duct is 3.0 mm. long

and 0.1 mm. in diameter. The spermatheca is thin walled, spherical and 1.0 mm. in diameter. A very slightly developed system of folds in the wall of the large hermaphroditic duct, close to and above its external opening, probably functions as a vulvar gland.

The spermatic portion of the duct is continued forward beyond the external opening as a deep groove along the side of the animal, downward and forward, to the penis opening, situated as usual on the right side of the head, just below the anterior tentacle. The penis is inclosed in an eversible, muscular sack, the posterior end of which is attached to the foot and the lower body wall by two groups of retractor muscles, a dorsal and a ventral set. The spermatic groove is continued along the inner wall of this sheath to its base, where the penis proper is attached, and is thence continued forward along the side of that organ to its tip. In its retracted condition the penis sack measures 7.0 mm. Its inner wall is thrown into a series of longitudinal folds, between two of which the spermatic groove is inclosed. This and the adjacent folds are sprinkled with brown pigment.

The proximal end of the sheath is occupied by the retracted penis, a slightly flattened, conical, muscular organ, 0.6 mm. in diameter at the base, and ca. 2.5 mm. long in its retracted condition. Along its whole length extends a deep furrow, the spermatic groove, continuous at its base with the groove upon the inner surface of its sheath. No trace can be made out of any armature upon any portion of the penis or its sheath, nor is there any specialized glandular area present.

THE ORGAN OF BOHADSCH.

The organ of Bohadsch, or hypobranchial gland, is spherical, somewhat flattened in form, of a whitish color, and has a diameter of 4.0 mm. In general aspect it presents the appearance of a close bunch of grapes, its surface being nodular in form, corresponding to the very large gland cells of which it is constituted. The gland opens externally by a single large duct, the orifice with tumid margins being situated upon a conspicuous elevation below the ctenidium and behind the reproductive opening.

Large gland cells similar in form to those of the hypobranchial gland are also found scattered in the mantle margin,

and doubtless contribute to the well known characteristic defensive secretion of these animals.

CIRCULATORY, EXCRETORY AND RESPIRATORY SYSTEMS.

The circulatory, excretory and respiratory systems of *Tethys cervina*, so far as studied, were not found to differ markedly from those of other species, and matters of familiar knowledge, and hence they will not be entered upon in this place.

Leland Stanford Junior Zoological Museum, Invertebrate Series No. 144.

TRIBE III. PLEUROBRANCHOIDEA.

Dorsal region covered by a large shield-like mantle, or notaeum. Shell external, internal or absent. Head distinct, with two pairs of tentacles. A single ctenidium on the right side, between the mantle and foot. Foot without parapodia. Genital duct diaulic, the male and female apertures contiguous. Visceral commissure short.

Family PLEUROBRANCHIDAE.

Mantle fleshy, stiffened by spicules, concealing wholly or partly the delicate haliotiform shell, if developed at all. Anterior tentacles united to form a frontal veil, posterior tentacles, or rhinophores, auriculate. Foot flattened, large. Radula multiserial, with no rhachidian teeth. Mandibles well developed, composed of many oblong plates arranged in tessellated pattern.

Genus PLEUROBRANCHUS Cuvier, 1805.

Pleurobranchus, Cuvier. Mémoire sur la Phyllidie et sur le Pleurobranche. Annales du Museum d'Histoire Naturelle, V, 1805, p. 266-276, Pl. 18, Figs. 1-6.

Berthella, Blainville. Manuel de Malacologie. 1825, p. 469, 627, Pl. XLIII, Fig. 1.

Pleurobranchus, Pilsbry. Tryon's Manual of Conchology, XVI, 1896, p. 191.

Pleurobranchus, Vayssière. Monographie des Pleurobranchidés. Ann. des Sciences Naturelles, Zoologie. Ser. 8, T. VIII, 1898, p. 279.

Pleurobranchus, Bergh. Malacologische Untersuchungen, IV. 1, 3, in Semper's Reisen im Archipel der Philippinen, VII, 1898, p. 117.

Body elliptical, mantle more or less developed, its borders free, the anterior border more or less emarginate; shell internal, calcareous or subcalcareous. Rhachis of ctenidium smooth. Male and female genital openings contiguous, or almost united. Mandibles made up of flattened, closely set elements.

Pleurobranchus agassizii Sp. Nov.

Plates XI and XII, Figs. 43-57.

Three small specimens of a *Pleurobranchus* were taken by Mr. Greeley at Riacho Doce, Alagoas. They were killed in formalin and afterward transferred to alcohol. The coloration of the animals in life was not noted; the color of the preserved specimens is a rather uniform pale, pinkish yellow. In two of the specimens a fine light brown mottling seemed to divide the dorsum into very minute polygonal areas, but even this trace of color gradually disappeared on their being transferred to alcohol.

EXTERNAL CHARACTERS.

Size. The three individuals measured 10, 11 and 8 mm. in total length, by 6, 6.5 and 5.0 mm. in width respectively. In each case the foot is somewhat contracted, the mantle but slightly so, the measurements in life probably exceeding the above somewhat. The length of the foot is 6.5, 6.0 and 5.5 mm., with corresponding widths of 4.0, 4.0 and 3.0 mm. in each case.

Body form. The body is arched, slightly depressed, oblong; the mantle broad, extending far beyond the foot throughout its entire circumference, though the strongly contracted posterior end of the foot, the rhinophores, and the frontal veil probably extend well beyond the mantle margin in the living animal. The mantle margin is very slightly emarginate above the tail. The surface of the dorsum is smooth, save for slight, irregular nodosities formed by unequal contraction. The mantle margin is moderately thick and very wide, being 2.0 mm. in width, its free edge being smooth.

Shell. The white calcareous shell (Pl. XI, fig. 43) shows plainly through the mantle in all the specimens. It is placed well forward, its anterior margin being above the head region, while the posterior portion covers the anterior two-thirds of the posterior visceral mass. In outline it is oblong, nearly linear, the lateral margins being nearly parallel. The anterior margin is more gently rounded than the posterior one, the spire very small, oblique, the whole shell being made up of about two turns, the outermost one very broad and flat, and forming almost the whole area of the shell. The lines of growth are plainly marked; the

inner and outer surfaces of the shell are quite smooth. The length of the shell varies in the three specimens from 4.2 mm. to 5.5 mm., its width from 2.5 mm. to 3.0 mm.

Foot. The foot is smooth, truncately rounded in front, more pointed behind. No well marked pedal gland is visible at its posterior end. The lateral margins of the foot are continuous, undulating, the anterior margin bilabiate, the lower lip much thicker than the upper, which bears a median notch. The dorsal surface of the foot margin is smooth, with no visible pigmentation, if any existed during life.

Head. The frontal veil is large, trapezoidal, its anterior, free margin smooth, nearly straight, the outer angles very slightly rounded, the external margin deeply auriculate. The width of the frontal veil in the three specimens is 4.0, 4.0 and 3.0 mm. respectively, the length being 1.5 mm. in all. The rhinophores (Pl. XII, fig. 57) are very large cylindro-conical organs, their bases contiguous, but not fused. Each is made up of a loosely rolled plate, the margins external, the lower one overlapping the upper. The margins are prolonged at the base into a considerable flap, which is free. Just above and external to the base the very large eyes shine conspicuously through the integument.

Ctenidium. The branchial plume lies on the right side in the roomy space between foot and mantle, completely concealed by the latter. It measures one-half the total length of the body, being 5.0 mm. long in the largest specimen, while in the smallest one it is but 2.0 mm., i. e. one-fourth the body length. The posterior half of the plume is free from the body wall; the rhachis entirely smooth. The plume is bipinnate, bearing about twelve pinnules on each side, arranged alternately. The anal opening is situated above the posterior end of the base of the branchial plume.

INTERNAL ANATOMY.

Mandibles. The labial armature is made up of a pair of oblong mandibles of a light amber color in their anterior portion, becoming paler behind, borne upon the sides of the buccal opening. Their greatest length is 1.215 mm., their width 0.66 mm., being nearly twice as long as wide. The oblique anterior border is slightly narrower than the more rounded posterior one, the dor-

sal border is rounded, the ventral one is straight (Pl. XII, fig. 56). Each mandible is made up of closely set chitinous elements, arranged in some 72 transverse rows, each row containing about 35 platelets. The anterior portion of the platelets of each row overlaps the interspaces between the posterior portions of those in the preceding series, thus giving a close, tessellated appearance to the whole mandibular plate. The individual elements of the mandible are somewhat trapezoidal in form (Pl. XI, figs. 44-48). The anterior portion is prolonged above into a flattened hook, directed obliquely forward and upward, pointed at the tip, and bearing laterally three to six strong denticles. Immediately behind the denticles upon each side is borne a stout truncated lateral process, which is in contact with the corresponding process of the adjacent plate of either side. The lateral processes of a platelet are not, however, exactly opposite to each other, the dorsal one being slightly behind its fellow of the opposite side as a rule, thus causing a slight obliquity in the row of platelets across the mandible (Pl. XI, fig. 46). Toward the dorsal margin the platelets become progressively thinner, until at the margin itself they become flattened and scale like, the anterior hook and the lateral processes are lost, and the whole takes on a simple lozenge shape. The body of a typical platelet is thick, truncate posteriorly, and fits closely in with its fellows. A deep, narrow, median slit (Pl. XI, figs. 45, 46) bifurcates the ventral surface of the body of the platelet, extending backward nearly or fully one-half of its length, and is slightly dilated posteriorly. It does not extend through to the dorsal surface, but may be readily seen from above by a slight change of focus. This groove is well marked in all except the very youngest platelets, its location in these latter being overlapped by a granular mass, identified by Vayssi re as the remnants of the nucleus of the cell which generated the platelet.

The dimensions of these elements varies from the anterior to the posterior ends of each mandible, and from end to end of each transverse row. The length of a typical older platelet is 0.022 mm., its thickness 0.015 mm., and its width, inclusive of the lateral processes, 0.017 mm. At the posterior end of the mandible the length of a similarly situated platelet is 0.035 mm., and its width 0.019 mm.

Radula. The radula is nearly colorless, about one and one-half times as long as broad. The rhachis is narrow and naked, the lateral teeth are unciform, strongly hooked, and arranged in 48 rows, with from 42 to 50 teeth in each half row. The dental formula may hence be expressed as 42-50:0:42-50x48. The innermost tooth in each row (Pl. XI, fig. 52) is somewhat smaller than its neighbors, the remaining teeth being approximately of the same size, with the exception of the outermost ones, which decrease gradually in size, the last ones of the series becoming flattened and almost rudimentary (Pl. XI, fig. 49). The body of each tooth (Pl. XI, figs. 50-52) is oblong, flattened, slightly oblique, its posterior end truncate, in some cases emarginate or notched. The anterior end is rounded, the inner margin expanded into a flattened wing, which is overlapped by the next inner tooth, the outer margin being nearly straight. Viewed from below (Pl. XI, fig. 53) the bases are of a somewhat oval outline, becoming more linear toward the ends of the rows. A typical tooth, such as the one shown in side view in Pl. XI, fig. 50, taken from the middle of the 22d row, measures 0.025 mm. in total length of base, the height of the hook above the bottom of the base is 0.014 mm. The outermost tooth, such as is shown in fig. 49, of Pl. XI, taken from the 11th row, is 0.01 mm. in base length, its total height being 0.006 mm.

Viscera. The very poor preservation of the viscera precluded any satisfactory study of their structure and relations, their hard and brittle condition resisting all attempts at softening.

NERVOUS SYSTEM.

Central ganglia. The central nervous system is enveloped in a closely fitting connective tissue capsule, very difficult to remove, which also binds it closely to the buccal mass. The cerebro-pleural complex (Pl. XII, fig. 55) is closely fused, and the two sides are in such close contact in the median line that no commissures connecting them may be made out. No distinct line of demarcation can be made out between the cerebral and pleural moieties of the complex upon either side, nor is there any grouping of the nerve cells to correspond to such a division. The separation into two distinct ganglia as shown by Von Ihering ('77) for *Pl. meckeli* (fig. 8, Taf. II), does not here

obtain, the two ganglia being united into a single flattened mass, circular in outline, and having a diameter of 0.36 mm. The pedal ganglia are slightly smaller than the cerebro-pleural ones, being 0.3 mm. in diameter, and having the same flattened, spherical form. The eyes are very large, nearly spherical structures, 0.15 mm. in diameter, and borne upon very short optic nerves.

Connectives. The cerebro-pedal and pleuro-pedal connectives (Pl. XII, fig. 55, *c. p. con.*, *pl. p. con.*) are extremely short and can only be seen after carefully dissecting away the capsule and displacing the ganglia by gentle pressure upon the cover glass.

Otocysts. The otocysts, not represented in fig. 55 of Pl. XII, are spherical structures, 0.06 mm. in diameter. They are situated at the upper inner border of the inner face of the pedal ganglia, close to the cerebro-pedal connectives, and contain a large number of minute otoconia.

REPRODUCTIVE SYSTEM.

The glans penis is extruded in all three specimens. It is short and bluntly conical, and is surrounded at its base by a conspicuous fold of integument, which is continuous all around save at the posterior side, where its ends overlap with a deep fissure between them. Just within this fissure, and close to the posterior portion of the base of the glans penis is the female opening (Pl. XI, fig. 54, *v*). The exact relations of this opening with that of the duct of the nidamental-albumen gland could not be made out satisfactorily. They are very close together, the gland duct seeming to have a common external opening with the vagina, but the condition of the material made this and other points in the structure of the reproductive system uncertain. In sections the glans penis is circular, and there is no indication of an anterior wing-like appendage, such as is given by Vayssi re as a characteristic of his subgenus *Pleurobranchus* s. str. (Monog. '98, p. 307).

SYSTEMATIC POSITION.

There can be no doubt but that this species is distinct from the three Antillean forms described by M rch ('63), especially in the light of the careful anatomical description which Bergh

('97, '98b) has given of these forms. Its lack of agreement with *Pleurobranchus patagonicus* d'Orbigny, the only recorded species from the east coast of South America, is equally clear from Bergh's study of the anatomy of that species ('98a). Nor does it agree satisfactorily with the Antillean *Pleurobranchus lacteus* of Dall and Simpson ('99, p. 367) in external characters nor in shell. An anatomical study of the latter species is much to be desired, however, before certainty can be assured. In the meantime I must consider the present form a new species and have much pleasure in dedicating it to Professor Alexander Agassiz of Harvard University.

Type No. 145, Invertebrate Series, Leland Stanford Junior University Zoological Museum.

SUBORDER NUDIBRANCHIATA.

Naked hermaphroditic opisthobranchiate Mollusca, generally of symmetrical, slug-like form; without a shell in the adult state. Ctenidium and osphradium absent; symmetrical accessory respiratory appendages usually developed from the dorsal integument, rarely from the sides. Central nervous system concentrated. Radula usually strong, the teeth uni- or multiserial. Kidney not compact.

TRIBE I. DORIDOIDEA.

Genital duct triaular, liver completely inclosed in the visceral mass, female duct bifurcated. Anal aperture postero-median upon the dorsum, surrounded by the branchial rosette, or rarely between the perinotaeum and the foot.

Family DORIDIDAE.

Branchial plumes in an arc or circle, usually joined together at their bases, usually retractile into a common cavity. Rhinophores always with perfoliate clavus. Pharyngeal bulb never suctorial.

Subfamily DISCODORIDINAE.

Body not hard, depressed; the dorsum minutely granular. Mantle margin rather wide; tentacles digitiform; branchial plumes usually tri- or quadripinnate; foot rather wide.

Labial armature made up of minute, closely set rods. Rhachis of radula naked, the pleurae multidentate, the teeth hooked. Penis usually unarmed.

Three specimens of Dorididae were found in the collection, all of them being apparently new species.

Genus DISCODORIS, Bergh, 1877.

Discodoris, Bergh. Jahrbücher der deutschen Malakozoologischen Gesellschaft, IV, 1877, p. 61. —Malacologische Untersuchungen, XII, 1877, p. 518. —Mal. Unters. XV, 1884, p. 658. —Mal. Unters. Supplement Heft I, 1880, p. 47: II, 1881, p. 108. —Mal. Unters. XVII, 1890, p. 895. —System der Nudibranchiaten Gasteropoden. 1892, p. 102. —Challenger Reports, X, 1884, p. 92. —Die Opisthobranchiata der Siboga Expedition. 1905, p. 98.

Body rather soft, rounded or oval in outline; branchial aperture slightly crenulate, stellate or bilabiate; the anterior margin of the foot bilabiate, the upper lip more or less notched.

Prostate gland large.

***Discodoris branneri* Sp. Nov.**

Plate XII, figs. 58-65.

One specimen of this form was taken at Riacho Doce, Alagoas, and was preserved in formalin, followed by alcohol. The rhinophores and branchiae are completely retracted, the whole specimen being slightly contracted and rolled up. No notes accompanied it save that of locality alone.

EXTERNAL CHARACTERS.

Form. Color. The body is depressed, linear oblong with bluntly rounded anterior and posterior ends. The dorsum is minutely villous, being everywhere covered with minute conical papillae. The mantle edge is thin and broad, extending far beyond the margin of the foot, and is fully one-half the width of the latter in the preserved specimen. The general ground color of the dorsum is pinkish, with thickly scattered irregular blotches of brown everywhere over its surface. Along the sides of the dorsum is a longitudinal row of five or six larger black spots about equidistant from each other.

Foot. The foot is smooth, almost linear, its anterior and posterior ends bluntly rounded. The anterior margin of the foot is thickened, and deeply bilabiate, the upper lip bilobed by

a deep median notch. Its length is 24.0 mm., the width 12.0 mm. The ground color of the foot is pinkish, thickly set with irregular brownish blotches, apparently arranged at random, i. e. producing no definite color pattern. The largest of these blotches may reach a diameter of 1.0 mm., but the majority are much smaller.

Head. The head is retracted and bears two tapering conical oral tentacles, 2.5 mm. long, and with a basal diameter of 1.0 mm.

Rhinophores. The rhinophores are completely retracted within their sheaths, the margins of which are low and closely set with short slender papillae. The clavus of the rhinophore is stout, club shaped, and lamellate.

Branchiae. The branchiae are situated as usual upon the posterior mid-dorsal region, surrounding the anal papilla and the renal opening. They are six in number, tripinnate, and retractile within a deep branchial pocket, the margin of which is thin and slightly prominent.

Total length of the specimen 32.0 mm., its width 12.0 mm.

INTERNAL ANATOMY.

The dorsal wall of the body cavity is rather firm and thick, its peritoneal lining colorless, save for a pinkish tint, which is possessed by all the viscera in common.

ALIMENTARY SYSTEM.

The alimentary canal is of the general type of the crypto-branchiate Dorids. The pharyngeal bulb is conical, truncate in front, 3.5 mm. long, by 2.5 mm. wide, and 3.0 mm. in height, the radula sheath projecting behind and below as a rounded eminence. The mouth opening is of an inverted T shape, the labial disc being covered by a firm transparent cuticle.

Labial armature. Externally the opening is guarded on either side by a somewhat triangular, yellow plate, the apex of which is directed backward (Pl. XII, fig. 58). The anterior border of each of these labial plates is slightly convex, ca. 0.81 mm. long, the upper border is straight, 0.72 mm. long, and is separated from its fellow on the opposite side by a distance of from 0.05 to 0.06 mm. The posterior border is very slightly concave, 1.08 mm. in length, while the lower angle is rounded.

These mandibular plates are made up of slender closely set blunt rodlets, longest in front and decreasing in length toward the posterior border. Those of the anterior portion range up to 0.096 mm. in length (Pl. XII, fig. 59), and decrease regularly toward the posterior portion, where they are very short (Pl. XII, fig. 60), the average diameter of ca. 0.005 mm. remaining nearly the same throughout, the tips of the rodlets being slightly dilated to nearly the same extent also.

Radula. The radula is broad and short, deeply grooved longitudinally in the median line, the teeth of one sort, uniform in shape, strongly hooked, and arranged in 26 rows of from 45 to 48 teeth in each half row, the rhachis being destitute of teeth. The dental formula may hence be expressed as 45-48:0:45-48x26. The outermost two or three teeth of each row (Pl. XII, fig. 62) are slightly smaller than the remaining teeth of the row, the base of the outermost being about one-third the length of that of the others, the remaining teeth being practically of the same size until the innermost two are reached, which are again somewhat smaller. The average height of a typical tooth (Pl. XII, fig. 63) is 0.186 mm., the length of the base 0.15 mm. The general tint of the radula is a faint yellow, deepening posteriorly, while the anterior portion is colorless or nearly so.

Blood gland. Overlying the buccal mass is the blood gland, divided into two lobes, the largest being thick and rounded, about 2.0 mm. in diameter, and is situated in front of, and in contact with the central nervous system. The posterior lobe, immediately behind the anterior one, is much smaller, triangular in form, its base being directed forward, and has a length of 1.5 mm. and a breadth of 0.5 mm. at the broadest end.

Salivary glands. The salivary glands are long and strap-like, the anterior portion, 1.0 mm. in width, being coiled upon the posterior face of the pharyngeal bulb. Each narrows to 0.5 mm. in width as it passes through the nerve collar, and extends backward, below the viscera ventrally, for about one-half the total length of the animal.

Esophagus, stomach and intestine. The esophagus is short and wide, ca. 3.0 mm. long by 1.5 mm. in diameter, passing directly downward and backward to the stomach, into which it dilates. The latter organ lies in a deep notch in the anterior face of the

posterior visceral mass. It describes a C shaped loop upon itself, the pyloric end lying almost directly above the anterior portion. The anterior half of the intestine is large and dilated, being about 11.0 mm. long by 2.0 mm. in diameter. It courses obliquely upward and backward in a deep groove in the upper right side of the visceral mass, constricts suddenly to 0.5 mm. in diameter, and continues for about 11.0 mm. to the anal opening, situated at the summit of the anal papilla, in the center of the branchial circle.

Liver. The liver is of the usual Dorid form, bluntly conical, the apex lying posteriorly beneath the branchiae, the anterior end divided by a deep median groove into right and left lobes, between which the stomach is inclosed. The total length of the liver is 12.0 mm., its maximum diameter 6.5 mm. The dorsal surface of the organ is divided by two transverse sulci into three nearly equal lobules, their surface being diversified by an irregular system of complicated ridges and shallow grooves.

REPRODUCTIVE SYSTEM.

Hermaphroditic gland and duct. The hermaphroditic gland is relatively inconspicuous and thin, the specimen evidently not having been taken during its breeding season. It can be distinguished with difficulty from the upper surface of the liver which it closely covers. From the anterior border of its right lobe it gives rise to the long, narrow, whitish hermaphroditic duct (Pl. XII, fig. 65, *h. d.*) which courses forward and downward for a distance of ca. 3.5 mm., dilating into the long white hermaphroditic ampulla (Pl. XII, fig. 65, *h. amp.*). This latter organ is of considerable size, making up a large portion of the anterior genital mass. It is 10.0 mm. in length by 1.0 mm. in diameter, and is coiled in three to four close loops upon the posterior and outer face of the anterior genital mass. At its anterior end it divides at once into the spermatic duct (Pl. XII, fig. 65, *sp. d.*) and the oviduct (Pl. XII, fig. 65, *ov. d.*). The former is very short, passing almost at once into the apex of the heart-shaped pinkish prostate gland (Pl. XII, fig. 65, *pr. g.*), which occupies the posterior inner face of the anterior genital mass. From a deep median groove in its posterior face arises the slender vas deferens (Pl. XII, fig. 65, *v. d.*). The total length of the prostate gland is 4.0

mm., its greatest breadth 3.0 mm. and thickness 2.0 mm. Its surface is very finely lobulated.

Vas deferens and penis. The vas deferens courses straight forward and outward along the inner and anterior faces of the complex to the penis. Throughout its whole length it preserves a uniform diameter of 0.5 mm., dilating suddenly at its outer end into the penis. The penis is somewhat contracted and nearly spherical in form, about 2.25 mm. in diameter, the large conical glans (Pl. XII, fig. 65, *p.*) projecting externally. The latter is bluntly conical, its apex truncate, 2.0 mm. in length, 1.0 mm. in diameter at the base, and tapering to 0.5 mm. at the apex. The glans bears an armature of minute hooks, set in longitudinal rows, about 17 in number near the distal end of the glans and increasing to nearly 100 toward the base. The individual hooks (Pl. XII, fig. 64, *a, b*) are rather stout, the largest occurring near the base of the glans, and measuring 0.02 to 0.027 mm. in height, their basal dimensions being nearly the same.

Vagina and duct. The vagina and vaginal duct lie upon the upper anterior border of the anterior genital complex (Pl. XII, fig. 65, *vag.*), and are of about equal length. The distal vaginal portion is conical, thick walled, with a series of longitudinal ridges upon its external surface, separated by shallow grooves, united at intervals transversely, giving the surface a somewhat lobulated appearance, which is due to internal glandular structures. In sections through the vagina and its duct the wall is seen to be made up of two conspicuous layers, an outer muscular one, consisting mainly of fibres arranged in a circular direction, and of nearly uniform thickness, throughout the whole length of the vagina and its duct, varying but slightly from about 0.045 mm. An inconspicuous submucous layer of connective tissue bears the innermost coat, the mucous layer, which is made up of a layer of columnar epithelial cells, distended with secretion products. This mucous layer is thrown into closely crowded leaf-like longitudinal folds, about twenty in number in the proximal portion of the vagina, and increasing to some fifty or more in the distal extremity. These folds range in height from 0.09 mm. to 0.24 mm. in the proximal and distal portions respectively. The narrow central lumen, left free from the folds, is filled with a coagulated mucous-like secretion.

The vaginal duct is whitish, muscular, of nearly uniform diameter, and 4.0 mm. in length. It describes a loop (Pl. XII, fig. 65), returning upon itself and opening into the spermatheca (Pl. XII, 65, *spth.*), which is a conspicuous dark spherical structure, 2.0 mm. in diameter, lying in the mid-dorsal region of the anterior genital complex. Upon its dorso-anterior face is the common opening of the vaginal and the uterine ducts, concealed by the overlapping proximal end of the vagina. The uterine duct (Pl. XII, fig. 65, *u. d.*) is slightly the more slender of the two, and passes obliquely forward along the inner face of the nidamental gland, beneath the sack like spermatocyst, which is doubled above it. Near the anterior end of the nidamental gland the uterine duct receives the short slender duct of the spermatocyst (Pl. XII, fig. 65, *sp. c.*), an elongated pear-shaped organ of a whitish color, 1.5 mm. in length by 1.0 mm. in diameter, and closely packed with spermatozoa. Its slender duct is slightly less than one-half the length of the cyst itself.

Nidamental gland. The uterine duct passes into the anterior end of the nidamental gland (Pl. XII, fig. 65, *n. a. c.*), immediately after receiving the duct of the spermatocyst, and at a point not far from the entrance of the oviduct, which joins the anterior end of the hermaphroditic ampulla to the nidamental gland. In most Dorididae the greater portion of the anterior genital complex is made up usually of the nidamental and the albumen glands. In this individual the two glands in question form but a very small portion of the whole, being but 2.0 mm. in extreme length by 1.2 mm. in width and 1.0 mm. in thickness. This proportion may possibly be due to absence of secretory activity in a non-breeding season, or to non-maturity. The surface of the nidamental gland is finely sculptured with minute ridges and depressions, is pinkish in color, and opens externally, immediately below and behind the opening of the vagina, by means of a broad duct (Pl. XII, fig. 65, *n. d.*), 1.5 mm. in length. The albumen gland is included in the windings of the nidamental gland, being exposed as a small oval area, 1.0 mm. in length by 0.3 mm. in width, upon the upper face of the larger gland. At the anterior border of this area is found the entrance of the uterine duct.

The systematic position of this species presents some difficulties due mainly to the well-developed penis armature, a

character not present in the genus *Discodoris*. In this respect it resembles *Carminodoris*, from which, however, it differs strongly in other features, notably in the granular, almost velvety notæum. For the present I deem it best to consider it a species of *Discodoris* until the study of further material may warrant a different disposition, rather than to create for it a separate genus based upon this character alone.

Some thirty or more species of *Discodoris* have been described, mostly inhabiting the Pacific and Indian oceans. But five of these, *D. notha* Bergh, *D. muta* Bergh, *D. indecora* Bergh, *D. tristis* Bergh and *D. edwardsi* Vayssièrè are from the Atlantic, the first four from the Antilles, the Azores and the Cape Verd Islands, the last from the Morocco coast. From all these the present species may be distinguished readily.

I take great pleasure in dedicating this new species to my esteemed colleague, Professor J. C. Branner, the originator and leader of the Branner-Agassiz expedition.

Type No. 146 Invertebrate Series, Leland Stanford Junior University Zoological Museum.

***Discodoris voniheringi* Sp. Nov.**

Plates XIII, XIV, XV; figs. 66-76.

One specimen of this new species was taken at Riacho Doce, Alagoas, July 20, 1899, by Mr. Greeley. No color notes accompanied the specimen, which was killed in formalin, afterward followed by alcohol.

EXTERNAL CHARACTERS

Form. The general body form is depressed, elongate, elliptical, the ends equally rounded, the mantle margins rather wide and thin, projecting far beyond the edge of the foot, the submarginal space nearly equalling the width of the foot itself.

Color. The ground color of the dorsum is pinkish gray, sprinkled everywhere with minute dark brown, or black spots. The under surface of the mantle and the sides of the body are a lighter pinkish, thickly sprinkled with minute dark spots, giving the surface a dusty appearance. Upon the under surface of the mantle on either side is borne a longitudinal series of three to four large round brownish blotches about midway between the mantle edge and the sides of the body. The largest of these spots reaches a diameter of 2.0 mm. Posteriorly this series is continued around above the top of the foot by a series of six or seven much smaller spots more irregularly disposed.

Dorsum. The dorsum is rather firm, tuberculate, being covered everywhere with low tubercles of varying size, inflated at their tips and much thicker than the slender cylindro-conical processes covering the dorsum of the preceeding species. The largest of these tubercles reach a diameter of 1.0 mm., and occupy the summits of slight elevations of the dorsal integument, having smaller and lower tubercles irregularly grouped around them.

Foot. The foot is smooth, rounded in front, its anterior margin deeply bilabiate, the upper lip projecting beyond the lower, and deeply notched to a depth of 0.5 mm. The sides of the foot are nearly parallel, gradually converging posteriorly to the bluntly rounded tail, which does not project beyond the

mantle edge. The edges of the foot are thin and crenulate. Its color is in general the same as that of the under surface of the mantle.

Head. The head is inconspicuous, the mouth a vertical slit, bearing upon either side long slender finger-like oral tentacles, 1.5 mm. in length, their tips blunt and curving forward.

Rhinophores. The rhinophores are brownish black, deeply retractile within conspicuous sheaths, with high tuberculate margins, the tubercles being of the same type as those of the general dorsal area. The sheaths reach a height of 1.0 mm., the whole slightly retracted rhinophore has a height of 2.5 mm. The clavus is of the usual club shape, perfoliate, with ca. 25 leaves on each side. The dark pigment is especially concentrated on the strong stalk of the rhinophore, where it forms a circular band, immediately below the clavus.

Branchiae. The branchiae are six in number, bipinnate, completely retractile into the branchial pocket, which bears a conspicuous lobulate margin, the low divisions of which carry tubercles similar to those of the dorsum. The anal and renal openings are situated as usual within the circle of the branchiae. The reproductive openings in the specimen were very small and inconspicuous.

Dimensions. Total length of the whole animal 20.0 mm., its width 14.5 mm., and maximum height 5.0 mm. Length of the foot 16.5 mm., its width 6.0 mm.; greatest width of the mantle margin 6.0 mm.

INTERNAL ANATOMY.

Blood Glands. The dorsal integument is rather soft and not thick. The pseudo-peritoneum is colorless, save in the region of the central nervous system where it is thickly sprinkled with minute, dark brown spots. The phagocytic blood glands, two in number lie directly in contact with the central nervous system; the anterior larger one is elliptical in outline and rather thick, measuring 1.5 mm. in length by 1.0 mm. in width and 0.2 mm. in thickness, and is dark gray in color, being sprinkled with minute black spots. Its dorsal surface is arched, the ventral concave, while the general contour is smooth throughout. It lies directly in front of the cerebral ganglia upon the pharyngeal bulb. The

posterior lobe is very much smaller and thinner, and lies transversely, its anterior border in contact with the central nervous system. It is somewhat reniform in shape, measuring 0.7 mm. in transverse by 0.3 mm. in longitudinal diameter.

ALIMENTARY SYSTEM.

Labial armature. The oral tube is short and conical, 1.0 mm. in length, bearing a colorless cuticula. The labial armature is small, consisting of a median plate, 0.735 mm. in length by 0.135 mm. in greatest width, and of two triangular lateral plates, 0.63 mm. in greatest length by 0.3 mm. in width (Pl. XIII, fig. 66). The median plate is elongate, spear-shaped, and is made up of closely set granular thickenings of the cuticle of varying size. Its median portion is marked by a narrow line in which the thickenings are much less numerous and are smaller than on either side. In the densest regions these granulations may assume the aspect of very short blunt rodlets measuring up to 0.002 mm. in diameter, and approximately the same in height.

The median plate is set off from the lateral ones by a narrow strip of cuticle, nearly destitute of such elevations. The lateral plates are approximately right angled triangles in general outlines, the apex being directed backward, the perpendicular side parallel to the median plate. The granular thickenings forming these lateral plates are of the same general type as those of the median one, are very dense in the central portions and merge off gradually toward the periphery into the thickened cuticula surrounding them.

Radula. The pharyngeal bulb is large and strong, 3.0 mm. in length by 2.0 mm. in height, in form truncately conical, the radula sheath projecting very slightly behind and below. The radula is broad, short, and deeply grooved, colorless in front, but becoming straw colored posteriorly. The teeth are in twenty-six rows, the rhachis of the radula is naked, and the pleural teeth vary in number from forty-six in the anterior half rows, to fifty in the posterior ones. The dental formula may be expressed 46-50:0:46-50x26. The teeth are all simple hooks in form, the majority except the outermost and innermost in each row, being of the same size and shape (Pl. XIII, figs. 67, 68; Pl. XV, fig. 75). The base of a typical average tooth measures 0.082 mm., the height

0.099 mm. The outermost tooth in each row is much smaller than the average, the base being much shorter, often nearly rudimentary, and the hook much more slender, as is shown in the slightly oblique view in fig. 69 of Pl. XIII. The next two teeth adjacent to the outermost, are progressively larger and form a transition to the remainder in the row. In like manner the innermost tooth of each row (Pl. XV, fig. 76) is much smaller than its fellows, the succeeding ones increasing in size, the typical dimensions being reached in the fifth or sixth tooth of each series. In front view all of the teeth of the radula are inclined toward the median line by a strong curve at their bases, the effect of which is partly nullified by a curve in the reverse direction in the middle and upper portion of the shaft (Pl. XIII, figs. 67, 68).

Visceral complex. The esophagus begins with a large dilation immediately behind the pharyngeal bulb. It recurves upon itself, narrows, passes through the commissural loop of the central nervous system, and, after a short course, opens into the stomach. The posterior visceral mass is bluntly conical, 8.0 mm. long by 5.5 mm. in maximum diameter, its lateral and lower surfaces convex, the upper one slightly flattened. The upper anterior margin is deeply notched for the reception of the stomach, the pyloric flexure of which is uppermost, passing gradually backward into the wide intestine, which courses along the dorsal surface of the liver to the anus. At the left of the pylorus lies the sack-like gall cyst of the liver, the greatest diameter of which, 1.4 mm., is nearly equal to that of the pylorus.

REPRODUCTIVE SYSTEM.

Hermaphroditic gland and duct. The hermaphroditic gland lies as usual upon the upper and anterior portion of the liver. The slight development of the reproductive cells rendered this gland relatively inconspicuous in the specimen. The hermaphroditic duct is short and slender, passing forward from the right anterior lobe of the hermaphroditic gland, and, after a course of ca. 1.5 mm., dilates into the long thick convoluted hermaphroditic ampulla (Pl. XIV, figs. 73, 74, *h. amp.*). This is closely coiled in a number of loops upon the posterior and lower border of the anterior genital complex, and makes up fully one-third the bulk of the latter. Its approximate length is 7.0 mm., with a fairly

uniform diameter of 0.7 mm. It is grayish white in color, and is densely packed with spermatozoa.

The wall of the hermaphroditic ampulla consists of a one-layered low epithelium, resting upon a thin subepithelial layer of connective tissue, which is in turn enveloped by a thin non-continuous layer of circularly disposed smooth muscle fibres. A loose connective tissue adventitia, not distinctly separated from the muscularis, forms the outermost layer. In places the whole wall is so reduced in thickness that it seems to be composed of the epithelium alone.

At the rounded posterior end of the nidamental gland the distal end of the hermaphroditic duct passes into the connective tissue along its anterior border, opening into a rather large cavity, 0.08 mm. in diameter, which is continued forward in the substance of the gland for some distance. Immediately after entering the nidamental-albumen gland complex the slender spermatic duct (Pl. XIV, figs. 73, 74, *sp. d.*) is given off, which, after its emergence from the gland, passes almost immediately into the substance of the prostate gland. These relations were made out in serial sections only, owing to the minuteness of the structures involved. It is of interest to note that the dense mass of spermatozoa, with which the hermaphroditic ampulla was filled, did not extend into the spermatic duct at all, but were confined to the extension of the ampulla into the nidamental-albumen gland complex.

Prostate gland. The prostate gland envelopes a U shaped loop of the vas deferens (Pl. XIV, figs. 73 and 74, *pr. g.*). It is 2.0 mm. in length, 1.0 mm. wide, somewhat prismatic in form, approximately triangular in cross section, its surface smooth and marked off into small lobules. Its posterior inner margin is curved, its inner and ventral surface convex, while its anterior distal portion is prolonged into two pointed lobes which inclose a portion of the spermatheca. It is enveloped by a very delicate capsule of connective tissue covering the closely packed lobules of the gland. The lumen is a more or less U shaped cavity, the walls of which are formed by a single layer of cubical to columnar, ciliated cells, passing over at the upper extremities of the U into the ciliated columnar epithelium of the vas deferens, and the spermatic duct respectively. Into this cavity open at intervals the very short branched tubular glands which make up the bulk of

the organ. The gland cells are large and clear, with large, deeply staining nuclei, the reticular cytoplasm being distended with a clear albuminous secretion, staining with difficulty. The poor fixation of the single specimen available precluded any satisfactory cytological study of the gland.

Vas deferens and penis. From the distal end of the prostate gland passes the vas deferens (Pl. XIV, figs. 73, 74, *v. d.*) a slender tube, ca. 3.0 mm. long, which courses with but few loopings outward and forward, terminating in the penis into which it rather suddenly dilates (Pl. XIV, figs. 73, 74, *p.*). It is lined with a single layer of slender columnar epithelium, surrounded by a thin layer of smooth muscle cells and a connective tissue adventitia. Toward the distal end the muscular elements become much increased, the wall of the praeputium being made up almost entirely of them. The penis was strongly retracted and curved upon itself, as was also the whole organ. It is bluntly cylindrical in shape, slightly tapering and is entirely destitute of any armature.

Vagina. The vagina (Pl. XIV, figs. 73, 74, *vag.*) is small and conical in general form, its length in the slightly contracted condition being 1.0 mm., with a maximum diameter of 0.5 mm. Its slender duct (Pl. XIV, fig. 74, *vag. d.*) passes directly inward to the central region of the dorsal face of the anterior genital complex where it opens into the spermatheca (Pl. XIV, fig. 74, *spth.*). In cross section about midway of its length it has a diameter of 0.097 mm., of which 0.052 mm. is occupied by the lumen. The lining is formed by a single layer of cubical epithelium bearing long cilia, in the distal portion elevated into long ridges, which become lower and disappear in the proximal portion. The muscular coat is strongly developed, and consists of a circular and a longitudinal layer, enclosed externally by a connective tissue adventitia.

Spermatheca and spermatocyst. The oblong flattened spermatheca lies in the center of the dorsal face of the anterior genital complex (Pl. XIV, figs. 73, 74, *spth.*). It is of a light amber color, is slightly flattened dorso-ventrally, measuring 0.435 mm. in its antero-posterior diameter by 0.315 mm. dorso-ventrally, with an extreme length of 0.46 mm. It is lined by a high columnar epithelium, apparently ciliated, but the preservation of the specimen renders this point uncertain. A connective tissue cap-

sule of considerable thickness, intermingled with smooth muscle fibres, surrounds the organ. The vaginal and uterine ducts are united in a common entrance into the spermatheca. In fig. 71 of Pl. XIII is shown a reconstruction from sections with the relations of these ducts and of the adjacent organs. The vaginal duct, *vag. d.*, is shown in its proximal portion only, uniting with the uterine duct, *u. d.*, at their common entrance into the spermatheca, *spth.* The uterine duct describes two S shaped loops close together, receives the slender duct of the spermatocyst, *spc.*, and opens into the nidamental gland at its anterior end, and some distance from the anterior margin of the albumen gland. The spermatocyst is of an elongate pear shape, doubled upon itself, its greatest diameter being 0.19 mm., and its length 0.330 mm. It lies immediately in front of and external to the spermatheca (Pl. XIV, figs. 73 and 74, *spc.*).

Nidamental-albumen gland complex. The nidamental-albumen gland is rather small in proportion to the remainder of the anterior genital complex. It is ovoid in outline, the broader end being directed forward and outward. The upper surface is nearly plane, the under surface slightly convex. The surface is marked as usual by parallel convolutions, which are however, not very conspicuous, being quite faint on the central dorsal region occupied by the albumen gland. The duct of the nidamental gland appears upon the ventro-anterior surface (Pl. XIV, fig. 73, *n. d.*), is large, and slightly flattened dorso-ventrally. In cross section (Pl. XIII, fig. 70) its lumen is seen to be large, the dorsal ventral and anterior walls being thin, and of nearly equal thickness. The posterior wall bears two strong parallel longitudinal ridges, *d.* and *v.*, projecting into the lumen and forming a deep groove between them. At the distal end of the duct these two ridges coalesce, the deep furrow becoming reduced to a shallow groove upon the crest of a single ridge. As the duct approaches the gland proper, this groove widens out, the ventral ridge decreases and disappears, while the dorsal ridge merges into the roof of the lumen of the gland.

Upon the external surface there is but little indication of the division into nidamental and albumen glands, such as is usually seen in other *Dorididae*, but in sections the structural difference is clearly apparent. In Pl. XIII, fig. 71 the boundary

of the gland is approximately marked by the dotted oval line. It occupies the median posterior portion of the complex. The distal end of the hermaphroditic ampulla, *h. a.*, enters the connective tissue stroma of the gland at its posterior end, giving off the slender spermatic duct, *sp. d.*, almost at right angles, and then dilates into a broad cavity, 2.5 mm. in length and 0.1 mm. in diameter. Its wall is practically identical in structure with that of the hermaphroditic ampulla, and, like the latter organ, it is packed full of spermatozoa. It is probably to be regarded as a fertilization chamber, since it is here that the ova first come in contact with the spermatozoa from a different individual. Just beyond the middle third of the gland complex this cavity bends sharply at right angles, dilates somewhat, thence passes again in a course parallel with the long axis of the gland, narrowing rapidly to the exit of the uterine duct, *u. d.*, from the anterior end. Just as the above mentioned dilation begins to narrow, a more slender duct, 0.24 mm. in diameter, is given off at an acute angle, running sharply backward and ventrally, and opening into the cavity of the albumen gland at its anterior end. This cavity is irregularly pear-shaped in form, the broad end being turned forward and outward, its tip extending nearly to the proximal end of the gland complex. It is lined by a low cubical epithelium, with large spherical nuclei. Into it open on all sides at intervals the secretory alveoli of the albumen gland, which may be either single, or, as is usually the case, branched into a small number of divisions. The cells of the secretory alveoli are columnar, ca. 0.006 mm. in average height, with large conspicuous nuclei, but their preservation did not permit making out any further details of their structure. Dorsal to the entrance of the branch of the hermaphroditic duct into the cavity of the albumen gland, a somewhat broader duct passes forward into the cavity of the nidamental gland proper. This large cavity occupies the ventral portion of the nidamental gland throughout its whole extent, and receives the short blind glandular diverticula which form the mucous secretion. In general the cavity is undivided, save for a few irregular ramifications along its posterior and outer border into which secretory alveoli open. The lumen of the duct is lined with small cubical cells with large nuclei; in the posterior half of the gland these cubical cells are replaced by tall slender columnar

ones much similar to those of the terminal alveoli of the gland. An examination of fig. 72 of Pl. XIV may aid in a clearer perception of the relations of the above described cavities. It represents the principal ducts of the gland complex in side view, as reconstructed from serial sections, the glandular alveoli and other subordinate ramifications being left out for the sake of clearness. The dotted line represents the contour of the gland complex as seen from the front side. At the posterior end of the complex the large hermaphroditic ampulla, *h. amp.*, enters, gives off the slender spermatid duct, *sp. d.*, which emerges from the gland as seen in fig. 74 of Pl. XIV, the duct passing forward, dilating into the fertilization chamber, *f. ch.*, which makes a sharp, knee like turn upward, then narrowing rapidly, gives off the slender duct, *x*, to the albumen gland, and receives the uterine duct, *u. d.*, at the distal end of the gland complex. The duct *x*, corresponding doubtless to the oviduct in other Dorids, passes backward, and to the right, and opens into the cavity of the albumen gland, *l. alb.*, triangular in this side view, and terminating posteriorly in a blind blunt prolongation. At its antero-dorsal end this cavity passes into the duct connecting it with the cavity of the nidamental gland, *alb. d.*, and opening into the extreme anterior end of the latter at the exit of the nidamental duct. The ventrally placed large cavity, *l. nid.*, into which the alveoli of the nidamental gland pour their mucous secretion, extends backward to the posterior end of the gland complex. Its dorsal surface is concave, the ventral convex in the anterior half of the organ, posteriorly becoming flatter, and finally the concavity is shifted to the ventral side, the dorsal face being arched. From the anterior end of the cavity the broad nidamental duct, *n. d.*, arises and emerges from the gland complex. In the figure the space between these ducts and cavities and the bounding dotted line is to be thought of as filled with the closely packed glandular diverticula arising from the cavities of the nidamental and albumen glands respectively.

The architecture of these two glands appears to be simpler in this species than in most other Dorididae. From fig. 72 of Pl. XIV the path taken by the eggs in traversing the different ducts from the hermaphroditic ampulla to the nidamental duct, can be readily followed. No trace of a second duct from the

albumen gland to the duct of the nidamental gland, such as that described by Pohl ('95) for Polycera could be found.

The circulatory, respiratory, excretory and nervous systems of this species presented no marked differences from other *Discodoridinae*.

The above species, which is clearly different from any hitherto described, I dedicate to Professor Hermann Von Ihering, the able Director of the Museu Paulista, Sao Paulo, Brazil, and the pioneer in the study of the Opisthobranchiata of that country.

Type No. 147, Invertebrate Series, Leland Stanford Junior University Zoological Museum.

Subfamily DIAULULINAE.

Body neither hard nor soft; depressed or subdepressed; notaeum usually minutely villous, often silky; tentacles digitiform; branchial aperture rounded, crenulate, branchial leaves tripinnate; anterior margin of foot bilabiate, the upper lip notched. Labial armature none. Rhachis of radula naked. Pleurae multidentate, usually hooked. Penis usually unarmed.

Genus PELTODORIS, Bergh, 1879.

Peltodoris, Bergh. "Ueber die Gattung *Peltodoris*," Mittheilungen aus der Zoologischen Station zu Neapel, II, 2, 1879, p. 222. —Malacol. Untersuchungen, Sup. Heft I, 1880, p. 41. —Neue Nacktschnecken der Südsee, IV, Jour. Mus. Godeffroy, XIV, 1878. —Malacol. Unters., XVI, II, 1889, p. 815.

Body subdepressed, the circumference oval, subrigid, minutely granular above. Tentacles digitiform. Branchial aperture rounded, the branchiae of few leaves, usually tripinnate.

Labial armature none. Rhachis of radula naked, pleurae multidentate, the teeth hooked.

Prostate gland large. Penis and vagina unarmed.

The genus *Peltodoris* was established by Bergh in 1879 for the reception of the type species *P. atromaculata* Bergh, from the Mediterranean, and for a second species, *P. crucis* (Oersted), from the Antilles. The genus is much similar to *Discodoris*, differing in the less soft body, and especially in the unarmed labial disc. Whether such a slight difference is sufficient to establish a distinct genus or not may be a matter of doubt.

In this genus are placed the following species:

1. *Peltodoris atromaculata* Bergh.
Bay of Naples. Bergh l. c.
2. *Peltodoris crucis* (Oersted).
Antilles, St. Thomas, (Riise). Sainte Croix, (Oersted).
Journ. de Conchyliologie, III, 3, 1863.
3. *Peltodoris mauritiana* Bergh.
Mauritius Isl. Bergh, Mal. Unters. XVI, 2, p. 815.
4. *Peltodoris angulata* Eliot.
East Africa. Eliot, Proc. Zool. Soc. London, 1903.
5. *Peltodoris aurea* Eliot.
East Africa. Eliot l. c.

6. *Peltodoris rubescens* Bergh.

Malay Archipelago. Bergh, Siboga Exp. 1905.

To this list is to be added the following new species, taken by Mr. Greeley at Riacho Doce, Alagoas, July 28, 1899.

Peltodoris greeleyi Sp. Nov.

Plate XV, figs. 77-82.

But one specimen is in the collection, no notes save that of locality and date accompanying it. The animal was rolled up in a loose coil, and was apparently not much shrunken by the preserving fluid.

EXTERNAL CHARACTERS.

Color and form. The color of the alcoholic specimen is very pale yellowish pink everywhere, there being no special markings. The dorsum is villous, quite velvety to the touch and quite similar to *Diaulula* in this respect. It is equally rounded in front and behind, the general body shape being oblong elliptical, with the wide, rather fleshy mantle edges projecting well beyond the foot.

Branchiae and rhinophores. The thirteen branchial plumes are short, simply pinnate and arranged in a complete circle about the anus, which occupies the summit of a low papilla, the minute pore-like renal opening being situated as usual, a little to the front and right. The branchiae were completely retracted within the branchial pocket, the thin margin of which is prominent, minutely villous, and slightly inrolled. The antero-posterior diameter of the opening is 2.8 mm., the transverse slightly less. The margins of the sheath of the deeply retracted rhinophores are similarly villous. The clavus of the rhinophores is club shaped and perfoliate, with sixteen leaves on either side. The tentacles are short, conical and dorso-ventrally flattened.

Foot. The foot is broad and muscular, contracted, the anterior end rounded and bilabiate, the upper slightly notched.

Dimensions. The approximate length of the partly rolled up specimen is 18.0 mm., with a maximum width of 10.0 mm.

INTERNAL ANATOMY.

Integument. The dorsal integument is thin, strengthened everywhere with minute spicules. Around the base of each papilla of the velvety surface of the dorsum is arranged a radial

series of short, rod like spicules which are continued up into the papilla to its summit. The minute papilla, which lend to the surface of the dorsum its velvety appearance, are supported by a large number of spicules, distinguishable into two classes. In the axial portion of each papilla are found four to eight stout, blunt, cylindrical spicules at right angles to the general body surface. Placed obliquely around these in a radiate manner, their central tips forming a close ring at the summit of the papilla, are a variable number of more slender, pointed spicules of the type generally found throughout the thickness of the integument (Pl. XV, fig. 77). The average length of the central spicules is 0.07 mm., their diameter 0.006 mm., while the oblique spicules average 0.11 mm. in length and 0.004 mm. in diameter.

The pseudo-peritoneum is colorless throughout, all the viscera being covered with a delicate sheet of connective tissue. Loosely attached to the dorsal surface of the central nervous system is the bilobed blood gland, very thin and flat, its anterior lobe being much smaller than the posterior one.

ALIMENTARY SYSTEM.

The oral tube is short, broad and muscular, 1.25 mm. long by 1.75 mm. wide, partly everted through the mouth opening. No trace of a specialized labial armature was present other than the simple cuticular thickening.

Radula. The pharyngeal bulb is a nearly spherical mass, 2.1 mm. in diameter, the radula sheath forming but a slight prominence upon the lower, posterior surface. The radula is broad, short and deeply grooved. The teeth are in 49 rows, of which the first, the oldest, are more or less worn away and incomplete. The rhachis is naked, the pleurae, 60 in number on each side, are strongly hooked, and of a similar shape throughout. The bases are moderately thick and heavy, the hooks blunt and flattened (Pl. XV, figs. 78, 81). The shaft and hook of each tooth lie in the same plane, the tip of the hook not being directed toward one side as is usually the case. The dimensions of a typical tooth are: length of base 0.082 mm., height of hook 0.049 mm., width of base 0.005 mm. The outermost tooth of each row is smaller than the remaining ones (Pl. XV, fig. 79), as are also the innermost pleurae (Pl. XV, fig. 80). The

dental formula for the whole radula may be expressed as 60:0:60x49.

Visceral complex. The salivary glands are short and broad, 2.5 mm. in length, scarcely extending beyond the circumesophageal ring of the central nervous system. The esophagus is short and wide, passing downward and backward into the large stomach, which lies in the usual V shaped groove in the upper anterior border of the liver. The stomach is broadly wedge shaped above, 4.5 mm. in length, 3.0 mm. wide and 2.25 mm. in depth, presenting a somewhat triangular cross section. The esophagus enters at its lower anterior border, the intestine arising from the upper posterior end and passing backward to the anus, lying in a groove in the upper surface of the liver throughout its course. The latter organ presents the form of a blunt cone, the anterior end deeply notched for the reception of the stomach, and faceted by the pressure of the anterior genital complex. The cavity of the liver opens widely into that of the stomach on the ventral median line, immediately behind the opening of the esophagus. No bile cyst is present.

REPRODUCTIVE SYSTEM.

Hermaphroditic gland and duct. The surface of the liver is covered everywhere save on the central portion of the gastric groove, the anterior face and the antero-ventral surface by the ramifications of the hermaphroditic gland. Its duct arises by the union of a number of delicate tubules from the lobules of the mid-dorsal face, immediately behind the stomach. It courses forward and downward, between the right surface of the stomach and the anterior lobe of the liver, for a distance of 3.5 mm. and dilates into the white hermaphroditic ampulla on the lower surface of the anterior genital mass (Pl. XV, fig. 82, *h. a.*).

Anterior genital complex. The organs of this complex are very compact, convex upon the outer and inner surfaces, in lateral view oval, from above more pointed posteriorly than in front. The extreme length of the complex is 4.6 mm., its width 2.5 mm., and height 3.5 mm. Its inner face bears a shallow broad groove, deepening toward the upper margin. Anterior to this groove and forming a large part of its anterior wall is a smooth, light brown surface, the wall of the spermatheca (Pl.

XV, fig. 82, *spth.*). Below, wedged in between the spermatheca in front and the albumen gland behind, appears the surface of the glistening white hermaphroditic ampulla. Encircling the spermatheca and this ampulla is a lobulated mass, the prostate gland (Pl. XV, fig. 82, *pr.*). Posterior to the hermaphroditic ampulla and the spermatheca, the inner face of the anterior genital mass is made up principally of the albumen gland, finely convoluted and of a light yellow color, surrounded above, behind and below by the thicker convolutions of the pinkish nidamental gland. The lower posterior border of the complex is occupied by a broad convolution of the nidamental gland, which is of a reddish hue, markedly distinct from the remainder of the mass. In the figure 82 of Plate XV, the nidamental and albumen glands have been dissected away, and are not shown.

Hermaphroditic ampulla. The hermaphroditic duct dilates into its glistening white ampulla, midway of the inner face of the anterior genital complex. This ampulla is somewhat lunate in form, curving downward in a groove between the spermatheca and the albumen gland, thence outward and upward upon the external face of the complex to a point immediately below and in front of the spermatocyst, where it narrows suddenly, gives off the spermatic duct (Pl. XV, fig. 82, *sp. d.*), and passes inward and upward into the nidamental gland.

Prostate gland and penis. The very short spermatic duct passes at once into the large lobulate prostate gland (Pl. XV, fig. 82, *pr.*), overlying and forming the whole of the front surface of the complex. From its superior surface is given off the relatively long vas defenens (Pl. XV, fig. 82, *v. def.*), which describes an irregular loop, free from the surface of the anterior genital mass, above its antero-median transverse groove, and passes downward and outward into the praeputium. The praeputium is 1.5 mm. long by 1.0 mm. in maximum width, tapering inward to the vas deferens. Within it is inclosed the retracted glans penis, cylindro-conical in form, its length 0.78 mm., its greatest diameter 0.16 mm., tapering gradually to a truncate tip with a terminal diameter of 0.009 mm., smooth and entirely unarmed.

Vagina and duct. Parallel to the praeputium and a little behind it pass the more slender vagina and vaginal duct. Their combined length is much less than that of the vas deferens and the praeputium. The vaginal duct (Pl. XV, fig. 82, *vag. d.*), passes inward between the prostate gland in front, and the spermatheca, opening into the latter after a course of ca. 2.0 mm. The spermatheca (Pl. XV, fig. 82, *spth.*) is ellipsoidal in form, 3.0 mm. in length by 2.5 mm. in width, and is covered almost entirely by the prostate gland and the adjacent organs, being exposed only for a small portion of its extent upon the inner face of the anterior genital complex. The uterine duct (Pl. XV, fig. 82, *u. d.*) is given off very close to the entrance of the vaginal duct, passes directly outward, becoming visible upon the outer surface of the mass, curves backward beneath the spermatocyst, and opens into the cavity of the nidamental gland. It receives, not far from its origin, the short duct of the pear shaped spermatocyst, which lies upon the upper outer border of the median portion of the complex. In length it measures 1.0 mm., in width 0.5 mm.

Owing to the loss of this portion of the material, which was being dissected at the time of the earthquake of April 18, 1906, I am unable to give any further details as to the structure of the prostate, nidamental and albumen glands.

The anatomy of the other organs of this species do not depart markedly from the other members of the genus.

This species is named in memory of Dr. Arthur W. Greeley, the zoologist of the expedition, whose untimely death cut short a life full of promise in his profession.

Type No. 148, Invertebrate Series, Leland Stanford Junior University Zoological Museum.

TRIBE II. AEOLIDOIDEA.

Genital duct diaulic, the male and female openings contiguous. Liver ramified, extending into the latero-dorsal integumentary papillae. Pharyngeal bulb bearing a pair of lateral mandibles.

Family AEOLIDIADAE.

Body slug-like, dorso-lateral papillae spindle, or club shaped, each terminating in a cnidosac armed with nematocysts. Head bearing a pair of simple tentacles, and a pair of simple or perfoliate rhinophores, non-retractile into sheaths. Foot elongate, the anterior angles frequently prolonged into tentacles.

Subfamily AEOLIDIANAE.

Body somewhat depressed or subdepressed. Dorsal papillae more or less compressed.

Masticatory margin of mandibles smooth or nearly so. Radula uniserial, the teeth wide, pectinate.

Penis unarmed.

Genus SPURILLA, Bergh, 1864.

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Body somewhat elongate, not depressed. Rhinophores perfoliate. Anterior angles of foot not prominent. Cerata cylindroconical, arranged in groups, each of which is borne upon a slight, crescentic, dorso-lateral elevation of the integument.

Masticatory margin of mandibles long, minutely denticulate, or smooth.

Radula uniserial, the teeth pectinate, emarginate in the center.

This genus was proposed by Bergh in 1864 for the reception of Delle Chiaje's *Eolis neapolitana* as the type species. In 1871 he transferred to this genus a second species, *Sp. sargassicola* (Kroyer), and in 1882 and 1885, in the papers cited above, made further additions to the knowledge of the anatomy of the type species, which had been already extensively studied by Trinchese in 1878. Vayssière added to this in his excellent researches upon the Opisthobranchs of the Gulf of Marseilles, in 1903 recognizing a third distinct species, *Sp. inornata* (A. Costa). The Siboga collections contained a fourth species, which was described by Bergh in 1905 in his beautiful work upon the Opisthobranchiata of that expedition.

At the present time the list of species described as belonging to this genus is the following:

1. *Spurilla neapolitana* Delle Chiaje).
Mediterranean, Cape Verd Islands.
2. *Spurilla sargassicola* (Kroyer).
Sargasso Sea, Atlantic Ocean.
3. *Spurilla inornata* (A. Costa).
Mediterranean.
4. *Spurilla orientalis* Bergh.
Kei Island, Malay Archipelago.

All three of these species are closely related, the first two being held by Bergh to be questionably distinct. The following description deals with the first member of this genus thus far taken from the West Atlantic. After a careful comparison of its structure with that of *Sp. neapolitana*, and with the description of the others, I am of the opinion that it represents a distinct species, though certainty in this regard can only be secured by the study of a series of specimens.

Spurilla braziliana Sp. Nov.

Plates XVI, XVII, XVIII and XIX; Figs. 83-96.

But one specimen was taken by the expedition, the locality label reading "Riacho Doce, Alagoas, July 28, 1899." The preservation of the specimen was rather poor, it having been killed in a distorted position, with the head, tentacles and rhinophores strongly contracted, and the posterior portion of the body re-curved dorsally. The cerata had nearly all fallen off, but were preserved in the bottle. The original color had entirely disappeared, nor were any notes taken as to the color, dimensions or appearance in life. The animal in the preserved condition had a uniform, pale pinkish coloration.

EXTERNAL CHARACTERS.

Dimensions. The total body length is circa 23.0 mm., of which the length of the foot makes up 18.5 mm., the quite distorted head region the remainder.

Body form. The general body form is slender and somewhat compressed, tapering posteriorly to a short bluntly pointed tail, the general body form being similar to that of the other species of the genus. The mouth is everted and reflexed, the whole head region being strongly contracted. The oral tentacles in their contracted state are tapering, with blunt extremities, their basal diameter being 0.5 mm., and approximate length 3.0 mm.

Rhinophores. The strongly contracted rhinophores are perfoliate, the clavus bearing eight prominent leaves, which alternate on the posterior side with an equal number of lower ones that extend forward, half way around the clavus from the posterior median line.

Cerata. The cerata are lanceolate, flattened, and variously curved, in part due to the action of the preservative, but also often showing the S shaped curves common in *Spurilla neapolitana*. The smaller cerata are more rounded and conical in form. The cerata are arranged in eight groups along the dorso-lateral margins of the body (Pl. XVII, figs. 90, 91). Each of the first five of these groups is made up of two slightly curved rows of cerata, the upper ends of the rows approaching each other and uniting to form an arc like figure, borne upon a slight integumentary elevation. The anterior limb of each of these arcs contains more

cerata than the posterior one, the number in both decreasing in each group from the first backward, until the posterior limb entirely disappears, the anterior row being alone represented in the groups from the sixth onward. In figs. 90 and 91 the bases of the cerata are outlined by small circles, indicating the relative size and positions of these groups. The number does not exactly correspond upon the two sides of the body for each group, but the difference is not marked, the total number for the right side being eighty, that for the left eighty-one. The distribution of the cerata in the anterior and posterior limbs of the groups is shown in the following tabulation.

Cerata Group	RIGHT SIDE		LEFT SIDE	
	Anterior Limb	Posterior Limb	Anterior Limb	Posterior Limb
1st group	11	7	13	8
2nd "	10	7	10	6
3rd "	8	5	8	7
4th "	7	4	9	5
5th "	6	3	6	2
6th "	5		4	
7th "	4		2	
8th "	3		1	
Totals	54	26	53	28

These figures may be expected to vary somewhat in individuals of different sizes, as they do also for the Mediterranean species.

The anterior limb of the first group begins in front of and below the bases of the rhinophores. The reproductive openings are situated close together, below the first arc of cerata on the right side; the anal opening is placed on a prominent tubular papilla, well up on the same side, and is included in the span of the second group. The opening is large, with slightly lobulated margins (Pl. XVI, fig. 88). The very minute renal opening is immediately in front of its base.

Foot. The foot is rather narrow, tapering posteriorly into a short bluntly pointed tail. The anterior margin is thickened, with a distinct, median groove, its outer angles are short and pointed (Pl. XVI, fig. 85). The total length of the foot is 18.5 mm., the diameter of its anterior portion 3.5 mm., narrowing to 3.0 mm. about midway of its length.

Pharyngeal bulb. The pharyngeal bulb is nearly oval in outline, broadest on its upper posterior border, the sides sloping toward each other below. In front the dark brown hinge portion of the mandibles is thickened and conspicuous. Its maximum measurements are, length 3.0 mm., breadth 1.8 mm., and height 1.8 mm., being fully one-third smaller than the pharyngeal bulb of specimens of *Sp. neapolitana* of the same dimensions of the body.

Mandibles. The mandibles (Pl. XVII, figs. 92, 93), are similar in general form to those of *Sp. neapolitana*, but decidedly smaller. They are elongate oval in outline, 3.0 mm. in greatest length by 2.0 mm. in greatest width. Each mandible is made up of three portions, the head, the body and the masticatory process. The head is massive, strongly arched in front and below, and bears the fulcrum, or hinge (Pl. XVII, figs. 92, *d.*, 93, *e.*), a strong dark yellow curved ridge, its concavity directed downward. In the left mandible the crest of this ridge is single (Pl. XVIII, fig. 95, *c.*), fitting into a groove between the diverging double crests of the corresponding ridge of its fellow of the opposite side (Pl. XVIII, fig. 94, *c.*).

The body is elliptical, thin, and strongly arched in front, less so behind, its whole extent strongly marked by the lines of growth, parallel to the posterior border. Its inner face is concave, the outer convex. The masticatory process is made up of a triangular lamina, widest behind, attached to the ventral margin of the body of the mandible. Its posterior end is free from the mandible and is separated from it by a deep sinus (Pl. XVII, figs. 92, 93, *c.*). The ventral margin (Pl. XVII, figs. 92, 93, *b.*) is much thickened and broader, and is prolonged forward, curving upward and backward to the posterior end of the fulcrum (Pl. XVIII, figs. 94, 95, *d.*). It serves as the masticatory margin of the mandible, and shows no trace of the denticles characteristic of the other species of *Spurilla*.

According to the descriptions and figures of Trinchese ('78) the single crest is found upon the fulcrum of the *right* mandible, the double crest upon the *left* one in *Spurilla neapolitana*, which is the reverse of the condition here described. In the preparations which I have made of the mandibles of *Sp. neapolitana* the relations of the single and double crests is the same as that which I have found in *Sp. brasiliana*. I am at a loss to explain the contradiction in results.

Radula. The radula is uniserial, consisting of a series of eighteen strongly arched slightly emarginate pectinate plates of an amber color. These plates increase rapidly and regularly in size from before backward, and present a slightly convex anterior face. The first five plates have their central denticles worn and broken, the last five are still inclosed in the radula sheath where they are developed. The dimensions of the individual teeth range from a basal width of 0.27 mm., and a height, measured from the middle of the base line to the top of the middle denticle, of 0.225 mm., in the first plate, to a width of 0.425 mm., and a height of 0.30 mm. in the eighteenth plate. The relative proportions are well shown in Pl. XVI, figs. 83 and 84, which illustrate the twelfth and the first plates of the radula respectively.

Each plate is slightly emarginate at its summit (Pl. XVI, fig. 89), but none so much so as to give the bilobed appearance figured by Bergh ('64, '71), Trinchese ('78) and Vayssi re ('88, '03) for the other species of this genus. The denticles are slender and lanceolate, the lateral ones slightly curved, the remainder straight, increasing in length from the sides upward, and reaching a maximum height about the eighth or tenth from the center. The central denticle is low and broad, usually with a small denticle next to it on either side, the succeeding ones increasing in length rapidly. The number of denticles in the first plate is 49:1:49; in the fifth 39:1:40; in the twelfth 57:1:53; in the fifteenth 61:1:63; and in the eighteenth 49:1:47, the increase in number thus being irregular. In a radula taken from an individual of *Sp. neapolitana* of the same body dimensions this increase in the number of denticles is much more regular, representative plates running as follows. First plate 18:1:15; fifth plate 23:1:23; tenth plate 34:1:34; twelfth plate 32:1:35; fifteenth plate 35:1:37; eighteenth plate 52:1:44; and in the twenty-sixth

and last plate 54:1:51. In this radula the basal diameter of the plates varied from 0.09 mm. in the first, to 0.55 mm. in the twenty-sixth. In *Sp. neapolitana* the three central denticles are very small or rudimentary, while in the Brazil species the central denticle is valid and much larger (Pl. XVI, fig. 89).

Salivary glands. The extremely long salivary glands are shown in figs. 86 and 87 of Pl. XVI. They have the same general appearance and relations as exhibited in the other species of *Spurilla*.

Central nervous system. The ganglia of the central nervous system are inclosed in a strong closely applied connective tissue capsule, from which in the specimen at hand the ganglia had in part shrunk away, the general preservation precluding any satisfactory detailed study of the cells and fibre tracts in sections, though the general relations could be readily made out. For comparison several specimens of *Sp. neapolitana* were also dissected. In general there is no great difference between the two species, but some marked discrepancies were noted between the Neapolitan species and the figures given for it by Bergh ('77), and by Trinchese ('78), especially in respect to the origins of the nerves. In Bergh's fig. 4, Pl. XII, the nerves appear to be represented in a diagrammatic fashion, they being neither numbered, nor mentioned in the text, the author manifestly laying most stress upon the form and grouping of the ganglia. In the earlier paper of Trinchese, "Nuovo Ricerche sull' Organizzazione del Cervello degli Eolididei," Memorie dell'Accademia delle Scienze dell'Istituto di Bologna, 1875, Serie III, T. V, he devotes his attention to certain peculiarities of the nerve cells as seen in preparations, cleared in glycerine and flattened under a cover glass, his figure of Tavola I giving but a faint idea of the actual form of the ganglia and the origins of their nerves. In his "Anatomia e Fisiologia della *Spurilla neapolitana*," cited above, this is corrected in the figures of Tavola XI, which present the best representations of the central nervous system of this Eolid yet published. In the figure of the same for *Sp. brasiliana*, given on Pl. XIX, fig. 96, I have adopted the designations used by Trinchese for the nerves for the sake of ease of comparison, though I must disagree with him as to the actual origin and

relations of some of these nerves in both the Brazilian and the Neapolitan forms.

In studying both species the central nervous system was carefully freed from its attachments, stained in Paracarmine, and cleared in glycerine. To facilitate microscopic examination, and to avoid unnecessary displacement of the parts concerned, a piece of glass rod was drawn out in a flame to the approximate diameter of the esophagus of the animal. A short bit of this was passed through the circumesophageal loop of the central nervous system, and the whole mounted on a slide having a suitable depression ground in it. The preparation may then be rotated and examined from all sides, without danger of disturbing the relations of its parts. The use of the Zeiss binocular dissecting microscope enormously facilitates the recognition of the relations of the ganglia and their nerves.

The dorsal portion of the nerve collar is made up of the fused cerebro-pleural ganglia (Pl. XIX, fig. 96, *c. pl. g.*), in contact along the median line, the cerebral portions being joined by the very short and broad cerebral commissure. The two ganglia are marked off from each other by a slight transverse constriction, dividing the complex into two approximately equal portions, the anterior, cerebral one being slightly larger than the posterior, pleural part. While in the main the nerve cells correspond in their distribution to these divisions, there is no middle region between the two entirely free from them. The length of the whole complex is 0.6 mm., the transverse diameter of each cerebral portion 0.345 mm., that of the pleural portion 0.315 mm.

Lateral to the esophagus are situated the ellipsoidal pedal ganglia (Pl. XIX, fig. 96, *ped. g.*), connected to the cerebro-pleural complex by the very short cerebro-pedal and pleuro-pedal connectives. The maximum length of the pedal ganglia is 0.33 mm., with an antero-posterior diameter of 0.21 mm., and a dorso-ventral diameter of 0.225 mm.

The ventral portion of the circumesophageal ring is made up of the commissures. These are three in number, two of which are united together in a common sheath, forming a broad band. In this band are included the broad pedal and the narrower sub-cerebral commissures (Pl. XIX, fig. 96, *ped. com.*). Separate from this, but close to it is the slightly longer pleural commissure

(Pl. XIX, fig. 96, *pl. com.*), taking its origin from the pleural portion of the cerebro-pleural complex. At a point about one-fourth of its length from the *left* side it gives off a moderately strong, unpaired nerve, the N. genitilis (Pl. XIX, fig. 96, *n. g.*). This is described and figured by Bergh as arising from the right side in *Sp. neapolitana*. In the Brazil species no ganglion cells were found at the origin of the nerve. To these three commissures should be added a fourth loop around the esophagus, which is separated from them by some distance. This is formed by the cerebro-buccal connectives and the buccal ganglia. These slender connectives (Pl. XIX, fig. 96, *cer. buc. con.*) arise from the cerebral ganglia just below and in front of the eyes. The buccal ganglia themselves are quite similar to those of the Neapolitan species. They are oval in form, 0.24 mm. long by 0.21 mm. broad, and are united by a very short (0.042 mm.) and broad commissure. A pair of small gastro-esophageal ganglia are closely united to them.

From the antero-dorsal portion of the cerebral ganglia arise the short stout olfactory nerves (Pl. XIX, fig. 96, *olf. n.*), which dilate into the very large elliptical olfactory ganglia at the base of the rhinophores. These nerves should, perhaps, be termed cerebro-olfactory connectives, the name olfactory nerves being reserved for the branches arising from the summit of the ganglia, which are distributed to the olfactory epithelium of the rhinophores.

The small optic ganglia, bearing the eyes (Pl. XIX, fig. 96, *e.*), lie upon the dorso-lateral margin of the cerebral ganglia, in direct contact with them, and above the origin of the cerebro-pedal connectives. Immediately behind these are the approximately spherical otocysts (Pl. XIX, fig. 96, *ot.*), 0.045 mm. in diameter, containing many small otoconia of an ellipsoidal shape. In sections the otocysts are seen to lie upon and behind a group of small ganglion cells, outside the limits of the cerebro-pleural complex, and probably to be regarded as an otic ganglion, but the preservation of the material precluded any decision as to their exact relationships.

Plate XIX, fig. 96 shows the origin of the nerves from the central nervous system in *Sp. braziliana*, being much the same as that given by Trinchese for *Sp. neapolitana*. Nerve VII

is worthy of separate notice, however. I am unable to confirm Trinchese's figures as to its origin in either species. He shows it as arising from the lower outer margin of the pedal ganglion as a pedal nerve. According to my preparations and sections it is a nerve from the cerebro-pleural complex, its fibres penetrating the capsule of the pedal ganglion at the upper inner border of the latter, immediately above the connectives joining the pedal ganglion to the cerebro-pleural complex. The fibres do not enter the pedal ganglion, however, but course directly into the pleural portion of the cerebro-pleural group. A similar relation may also be suspected in *Sp. inornata* in the case of the nerve numbered 6, in fig. 36 of Pl. III, in Vayssi re's "Recherches sur les Mollusques Opisthobranches du Golfe de Marseille, Suppl ment."

A decided asymmetry is to be noticed in the nerves of the pedal ganglia upon the two sides. Whether this has any special significance or not could not be determined by the dissection of but one specimen alone.

Counting the olfactory stalk as a nerve we have seven nerves given off from the cerebro-pleural complex, five of which arise from the cerebral portion, one from the intermediate zone between the cerebral and the pleural regions, and one from the pleural alone. As the optic and otic ganglia are sessile, they are not included in the above enumeration. From the pedal ganglion two large nerves arise, which are distributed to the sole of the foot. The peripheral distribution of the nerves was not worked out in detail, such an undertaking requiring much more material than was available.

REPRODUCTIVE SYSTEM.

The hermaphroditic gland is made up of eight spherical lobules, closely packed together and more or less flattened by mutual pressure. Six of these are paired, alternating more or less in position, while the seventh and eighth are unpaired. The glans penis is short and conical and entirely unarmed. The remaining organs of the reproductive system are not greatly different from those of the other species of *Spurilla*, all of which seem to show close similarity.

The general differences shown by this specimen in anatomical organization, especially as shown by the mandibles and radula,

seem sufficient to authorize its recognition as a member of a species distinct from the European ones already described. The name *Spurilla brasiliana* is here proposed for it.

Type No. 149, Invertebrate Series, Leland Stanford Junior University Zoological Museum.

114

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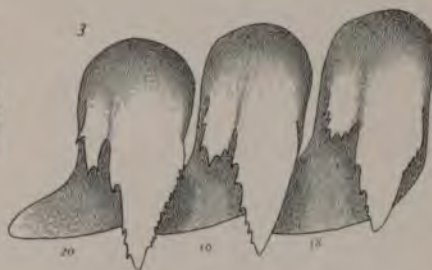
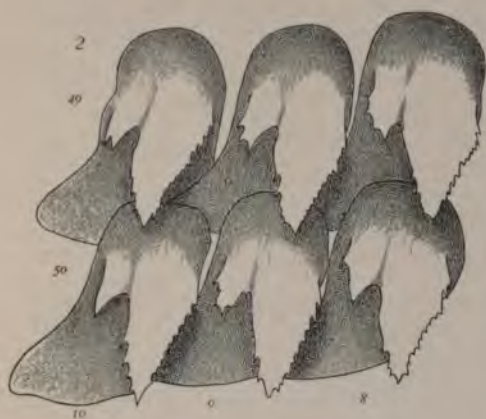
EXPLANATION OF PLATES.

All of the figures of Plates I-XIX were made by the aid of the Abbe Camera Lucida, and were redrawn in ink by Olive H. MacFarland. The line work of Plates II, VII and VIII was done by W. S. Atkinson.

PLATE I.

Tethys dactylomela (Rang).

- Fig. 1. Median and first lateral teeth of each side of 49th and 50th rows of radula. x 62.
- Fig. 2. 8th, 9th and 10th lateral teeth of 49th and 50th rows of radula. x 62.
- Fig. 3. 18th, 19th and 29th lateral teeth of 50th row of radula. x 62.
- Fig. 4. Outermost teeth, the 32nd to 37th laterals of 54th row. x 62.
- Fig. 5. A single typical lateral tooth. x 110.
- Fig. 6. Side view of the outer face of 5th laterals of the 49th and 50th rows. x 62.
- Fig. 7. Labial armature in surface view. *a*, anterior; *p*, posterior margin. x 195.



ad

PLATE II.

- Fig. 8. Central nervous system of *Tethys dactylomela* (Rang). *cer. g.*, cerebral ganglia; *ped. g.*, pedal ganglia; *pl. g.*, pleural ganglia; *buc. g.*, buccal ganglia; *c. p. con.*, cerebro-pedal connectives; *c. pl. con.*, cerebro-pleural connectives; *c. b. con.*, cerebro-buccal connectives; *pl. par. con.*, right pleuro-parietal connective; *pl. v. con.*, left pleuro-visceral connective; *p. com.*, pedal commissure; *p. p. com.*, parapedal commissure.

The nerves from each ganglion are numbered serially as described in the text, and are distinguished by the prefixed letter, *b.*, *c.*, *pl.*, or *p.*, indicating their respective ganglia, buccal, cerebral, pleural or pedal. x 10.5.

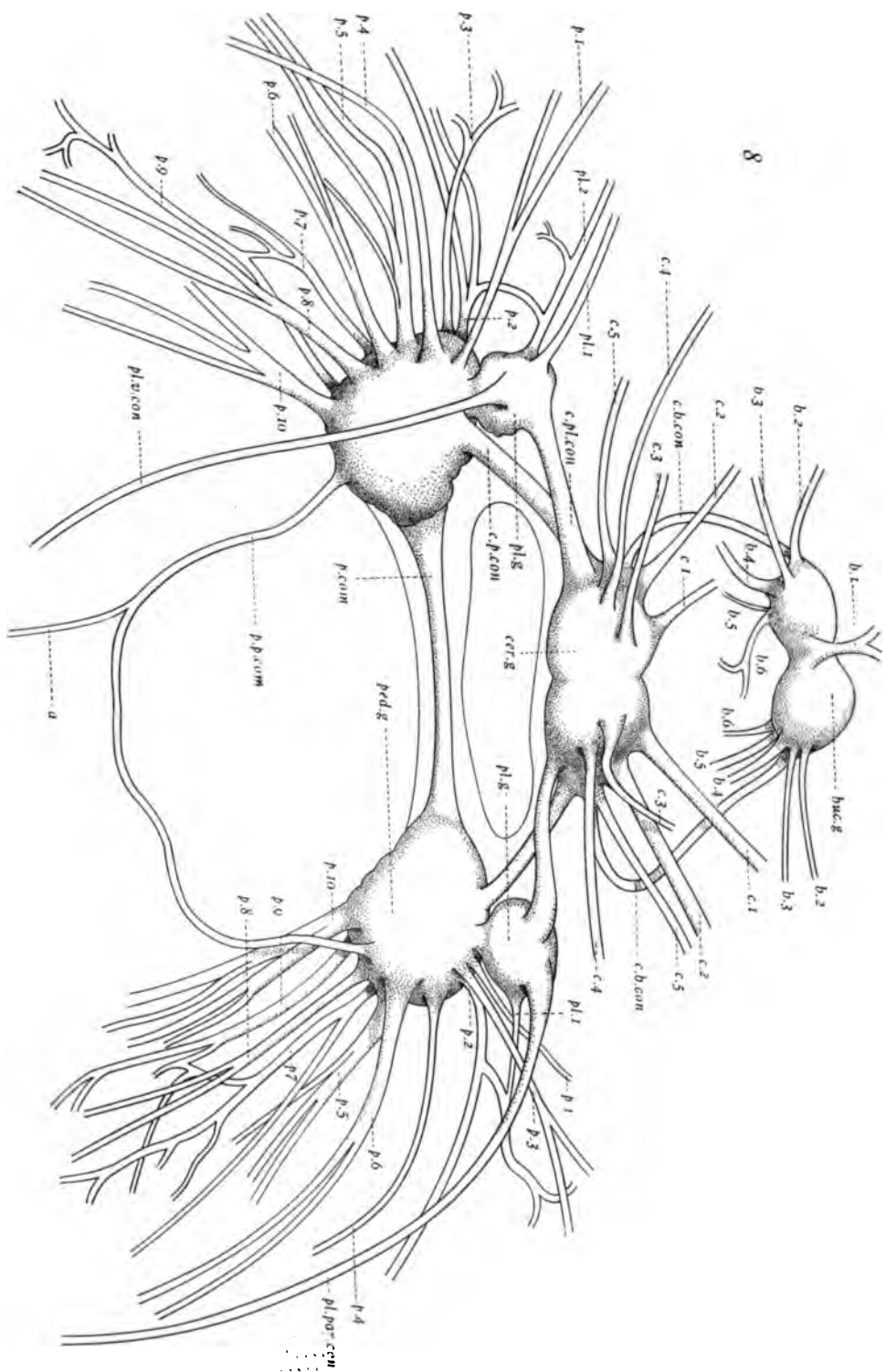


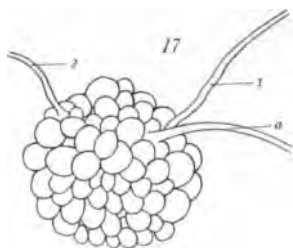
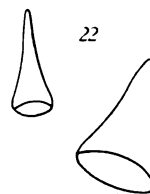
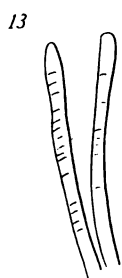
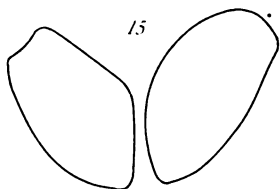
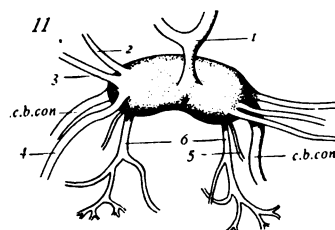
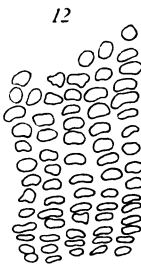
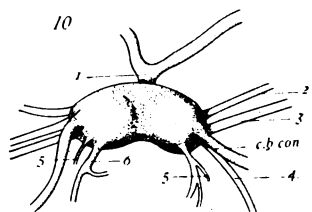
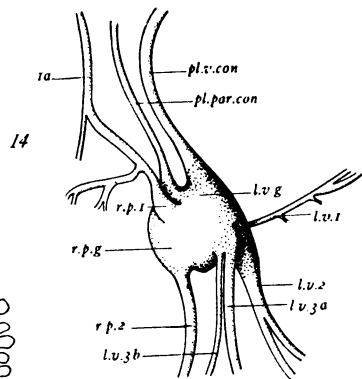
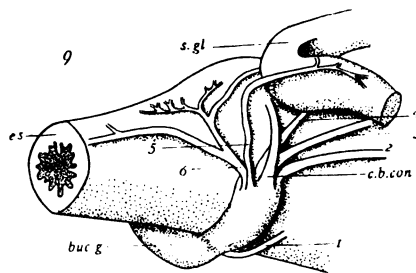
PLATE III.

Figs. 9-14, *Tethys dactylomela* (Rang).

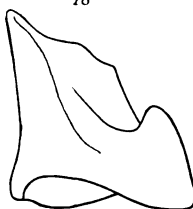
- Fig. 9. Buccal ganglia in situ, seen obliquely from below and the right side. *es.*, cut end of esophagus; *s. gl.*, right salivary gland, its severed distal end bent forward and to the right; *buc. g.*, buccal ganglia; *c. b. con.*, cerebro-buccal connective. The buccal nerves are numbered serially from 1 to 6. In this specimen the 5th and 6th nerves arose from a common trunk. x 8.
- Fig. 10. Buccal ganglia, ventro-posterior face. Lettering as in Fig. 9. x 8.
- Fig. 11. Buccal ganglia, dorso-anterior face. Lettering as in Fig. 9. x 8.
- Fig. 12. Posterior margin of labial armature showing outlines of bases of the rodlets. x 223.
- Fig. 13. Two elements of the labial armature from anterior margin of plate. x 137.
- Fig. 14. Parieto-visceral ganglion complex. *r. p. g.*, right parietal ganglion; *l. v. g.*, left visceral ganglion; *pl. par. con.*, right pleuro-parietal connective; *pl. v. con.*, left pleuro-visceral connective; *r. p. 1.*, 1st parietal, or vulvar nerve; *1a.*, its branch forming an anastomosis with the branch of the 3rd pedal nerve supplying the Organ of Bohadsch; *r. p. 2.*, second parietal, or osphradio-ctenidial nerve; *l. v. 1.*, first visceral nerve to vesicle of Swammerdam, the spermatocyst; *l. v. 2.*, second visceral nerve; *l. v. 3a.*, and *l. v. 3b.*, the two main branches of the third visceral nerve, in some specimens arising as distinct nerves, in others branching from a common trunk. x 8.

Figs. 15-22, *Tethys cervina* Dall and Simpson.

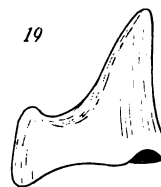
- Fig. 15. Outline of labial armature. x 8.
- Fig. 16. Rodlet from anterior portion of labial armature. x 183.
- Fig. 17. Surface view of Organ of Bohadsch, or hypobranchial gland. *a.*, artery; *1*, nerve from right pedal ganglion; *2*, nerve from left visceral ganglion. x 6.



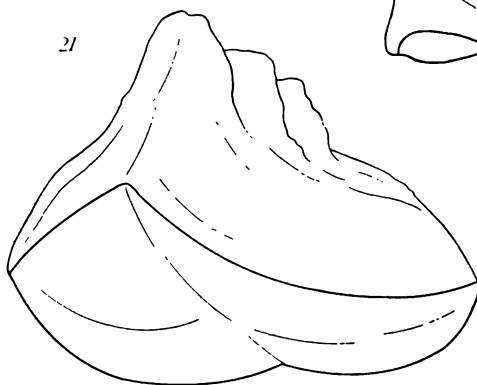
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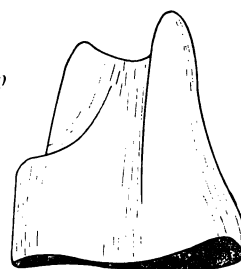
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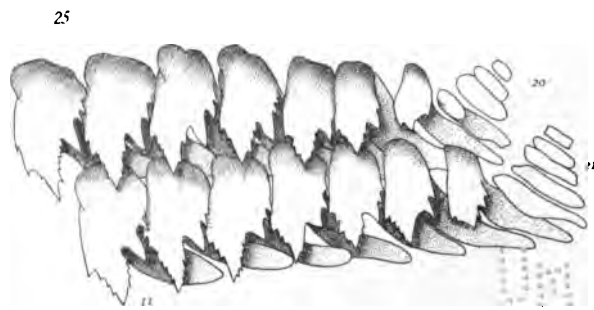
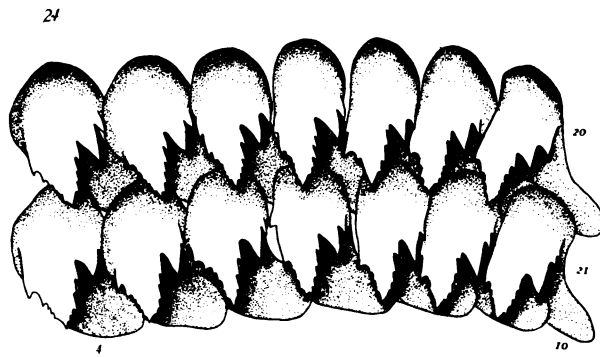
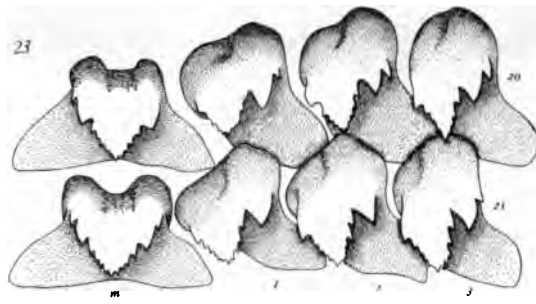


- Fig. 18. Anterior smaller tooth of second triturating stomach, obliquely from in front. x 24.
- Fig. 19. Similar tooth in lateral view. x 24.
- Fig. 20. Larger tooth of posterior series, obliquely from in front. x 24.
- Fig. 21. Largest tricuspid tooth of posterior series, obliquely from below, showing the convex basal surface with transverse median ventral groove. x 24.
- Fig. 22. Typical small, conical tooth from third triturating stomach. x 40.

PLATE IV.

Tethys cervina Dall and Simpson

- Fig. 23. Median and first three lateral teeth of twentieth and twenty-first rows of radula. x 62.
- Fig. 24. Fourth to tenth lateral teeth of same rows of radula. x 62.
- Fig. 25. Eleventh to twenty-second (outermost) lateral teeth of same rows. The three figures of this plate represent the whole extent of two rows of teeth from the middle to the side of the radula. x 62.



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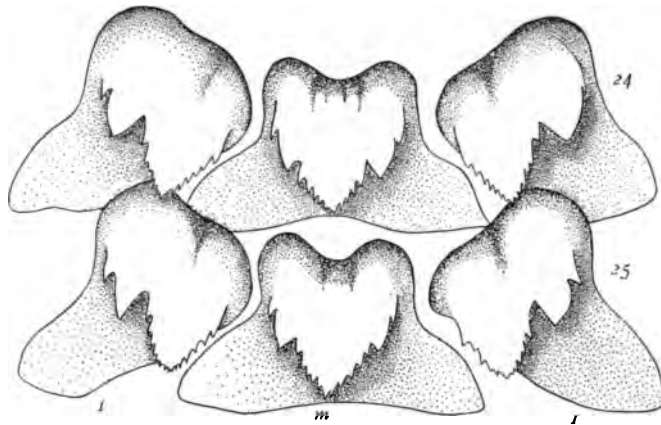


PLATE V.

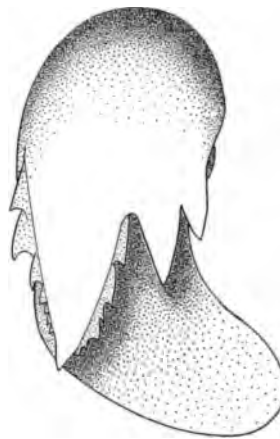
Tethys cervina Dall and Simpson.

- Fig. 26. Median and first lateral teeth on either side, 24th and 25th rows of radula. x 94.
- Fig. 27. Sixth, seventh and eighth lateral teeth, 24th and 25th rows of radula. x 94.
- Fig. 28. Seven outer lateral teeth of 29th and 30th rows of radula. x 94.
- Fig. 29. Detail of sixth lateral tooth of 20th row of radula. x 180.
- Fig. 30. Detail of 14th lateral tooth of 30th row, from opposite side of radula. x 180.

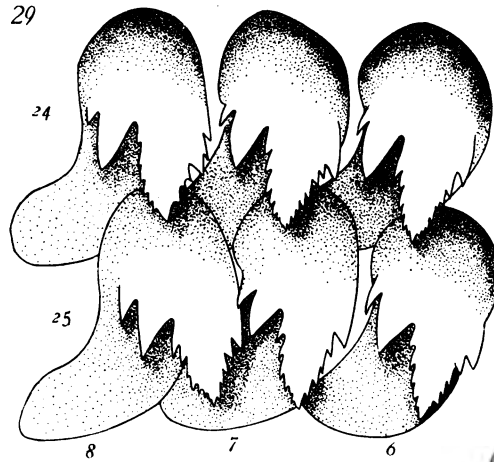
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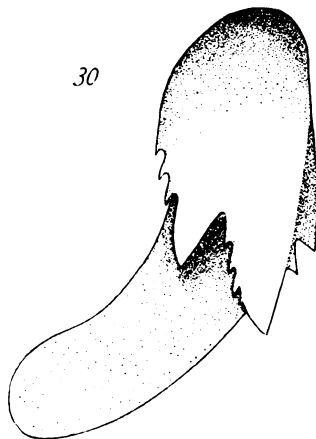
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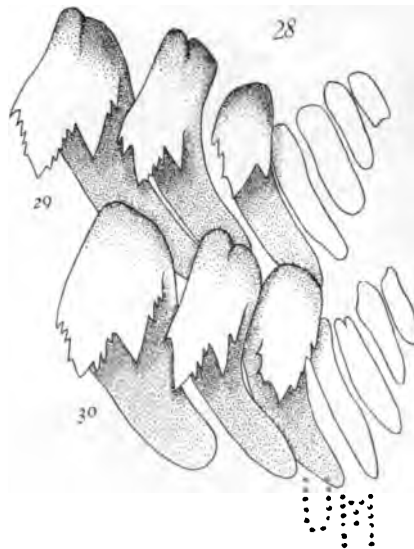
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PLATE VI.

Tethys cervina Dall and Simpson

- Fig. 31. Alimentary canal from below. The convolutions of the intestine are shown in their natural position, the liver having been dissected away. *e.*, lower end of the esophagus; *ingl.*, ingluvies, or first stomach; *m. st.*, muscular band of second, or grinding stomach; *3 st.*, third stomach; *h. coe.*, hepatic coecum; *int.*, intestine. x 3.
- Fig. 32. Relations of hepatic coecum and bile chamber. The wall of the lower portion of the third stomach and the first portion of the intestine have been cut away, showing the entrance of the large ducts of the liver in the opposite wall. The substance of the liver itself, which here almost entirely incloses the alimentary canal, has been dissected away. *h. coe.*, hepatic coecum; *l. r.*, the prolongation into the intestine as a longitudinal ridge of one of the folds in the wall of the hepatic coecum. x 5.
- Fig. 33. Reproductive system seen from below, the right border being above and to the left. *ov. t.*, ovotestis; *sm. h. d.*, small hermaphroditic duct; *sp. c.*, spermatocyst; *d. c.*, duct of Cuvier; *sp. p.*, spiral portion of genital duct; *c. p.*, convoluted portion of genital duct; *ov. sp. d.*, ovospermatic duct; *cop. d.*, copulatory duct; *spth.*, spermatotheca; *d. spth.*, its duct; *in.*, flap of the integument, upon the external face of which lies the vulvar aperture; *g. g.*, genital ganglion; *l. v. 3.*, third nerve from left visceral ganglion. x 8.

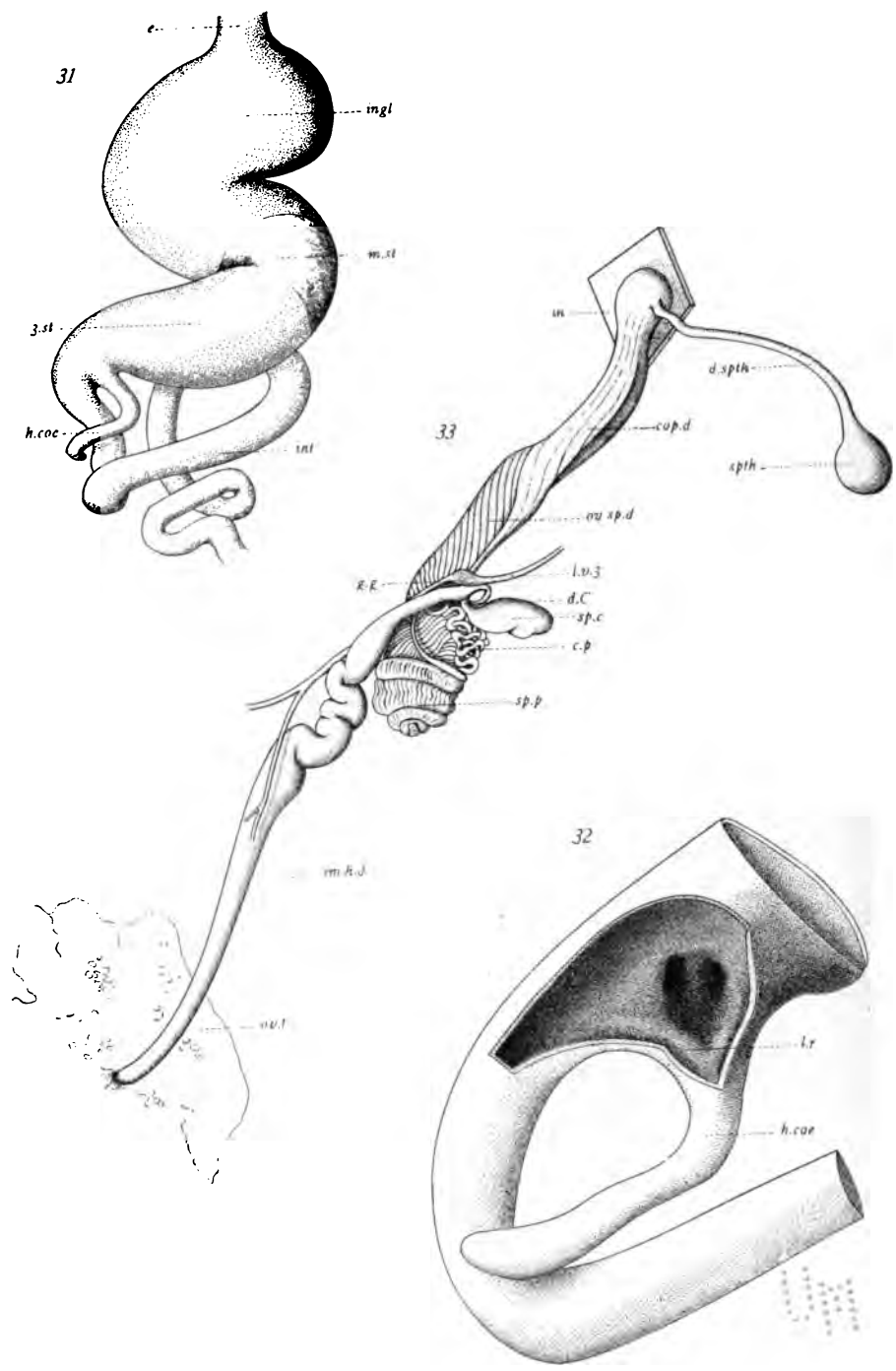


PLATE VII.

- Fig. 34. Central Nervous System of *Tethys cervina* Dall and Simpson, in dorsal view. *cer. g.*, cerebral ganglia; *ped. g.*, pedal ganglia; *pl. g.*, pleural ganglia; *c. p. con.*, cerebro-pedal connective; *c. pl. con.*, cerebro-pleural connective; *pl. par. con.*, right pleuro-parietal connective; *pl. v. con.*, left pleuro-visceral connective; *p. com.*, pedal commissure; *s. c. c.*, sub-cerebral commissure; *p. p. com.*, parapedal commissure. The nerves are numbered serially in the order of their origin from each ganglion. Those of the pleural ganglia are designated *pl. 1*, and *pl. 2*; those of the cerebral ganglion by the prefix *c* to their respective numbers, while the nerves of the pedal ganglia are designated by numerals alone. *x* Anastomosis of a branch of the third cerebral nerve, *c. 3*, of the right side with a branch of the second pedal, *2*. *e.*, eye. $\times 18$.

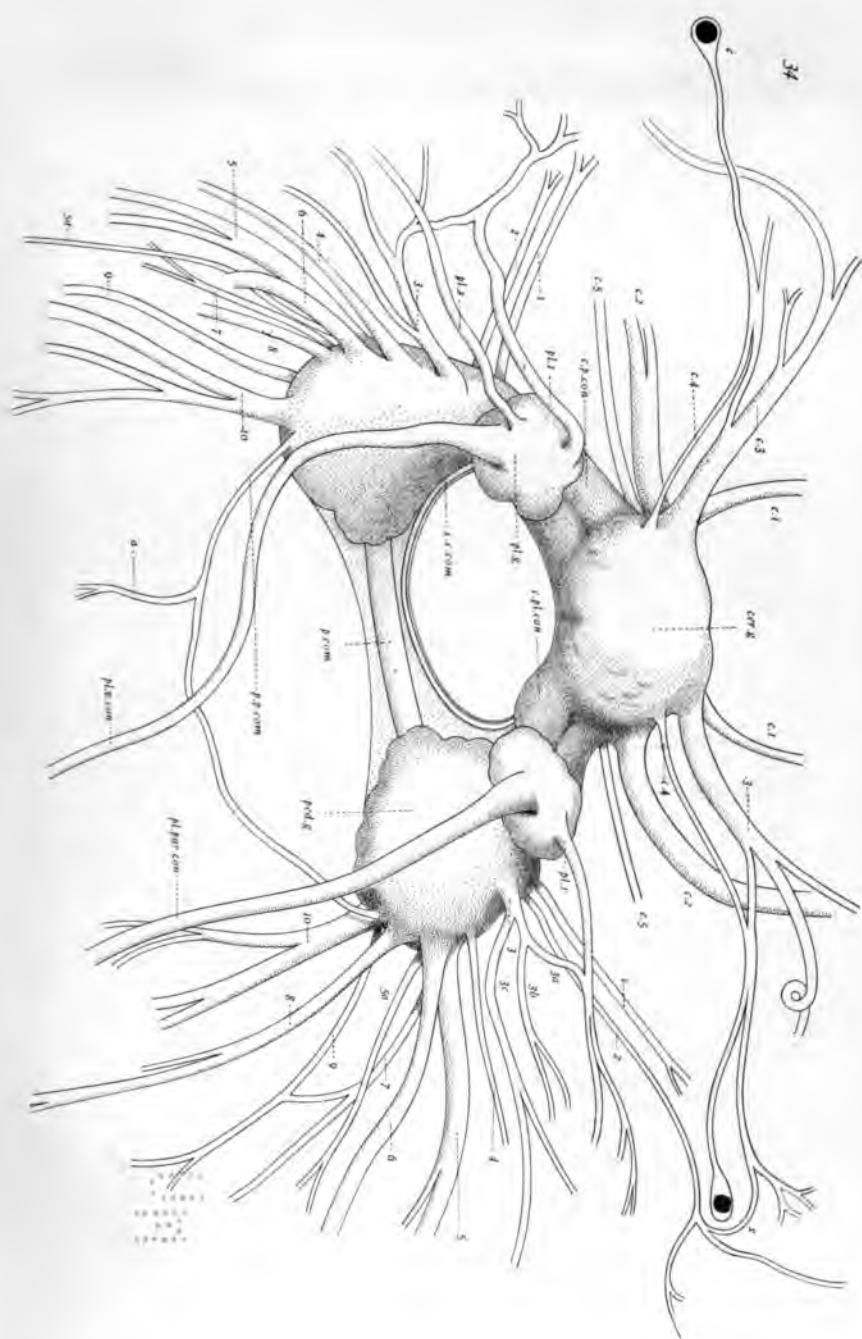
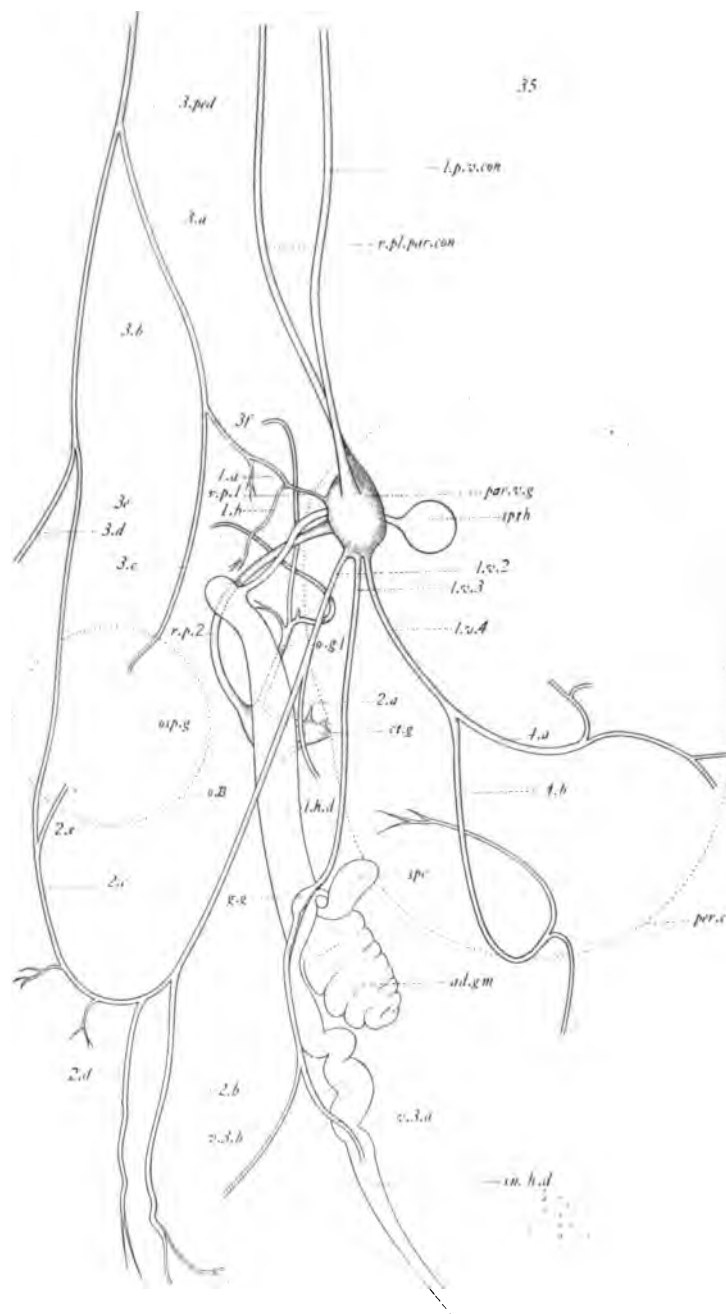


PLATE VIII.

Fig. 35. Parieto-visceral ganglia and nerves of *Tethys cervina* Dall and Simpson. The contours of the Organ of Bohadsch, *o. B.*, and the pericardial cavity, *per. c.*, are indicated in dotted lines, that of the reproductive system in light lines and unshaded. The anterior end of the animal is directed toward the upper side of the plate, the right of the animal corresponds to the left of the plate, the preparation being drawn in ventral view. *r. pl. par. con.*, right pleuro-parietal connective; *l. p. v. con.*, left pleuro-visceral connective; *par. v. g.*, the parieto-visceral ganglion complex, the ventral, or visceral moiety concealing the upper parietal portion; *r. p. l.*, vulvar nerve of right parietal ganglion, bifurcating into *1a.*, which anastomoses with a branch of the third pedal nerve, *3 ped.*, and *1b.*, the vulvar nerve proper; *r. p. 2*, osphradio-ctenidial nerve; *osp. g.*, osphradial ganglion; *o. g. 1.*, nerve to mantle; *ct. g.*, ctenidial ganglion; *l. v. 2.*, second nerve of left visceral ganglion; *2a.*, its hepatic branch; *2b.*, its main branch forking to siphon and anus; *2c.*, its recurrent branch to the peritoneum and the organ of Bojanus, anastomosing beyond the latter with a branch of the third pedal nerve; *3 ped.*, of the right side; *2d.*, its branch to the posterior peritoneum, etc.; *2e.*, the branch to the organ of Bojanus; *l. v. 3.*, third nerve of left visceral ganglion, supplying *g. g.*, the genital ganglion, and dividing into *v. 3a.*, and *v. 3b.*, to the small hermaphroditic duct and ovotestis, and to the dorsal body wall respectively, other delicate minor branches noted in the text not being represented. *l. v. 4.*, fourth nerve of left visceral ganglion, *4a.* its branch to ventricle and pericardium, *4b.* its branch to kidney, pericardium and auricle. *3 ped.*, main trunk of third pedal nerve of right side, bifurcating into *3a* and *3b*. *3a* gives off *3c* to the organ of Bohadsch, and *3f*, which anastomoses with a branch of the vulvar nerve, *1a*, and is distributed to the muscles of the body wall. *3b* sends off *3d* to the right retractor



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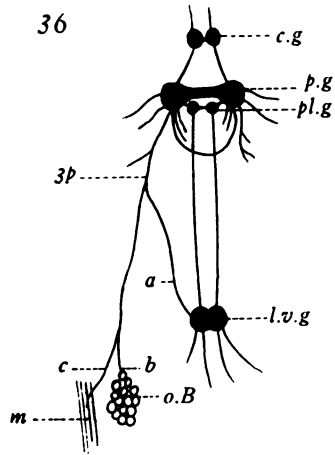
muscle of the head, and, as *3e*, anastomoses with the recurrent branch of the second nerve of the left visceral ganglion, *2c*. *sm. h. d.*, small hermaphroditic duct; *ad. g. m.*, adnexed genital mass; *sp. c.*, spermatocyst; *l. h. d.*, large hermaphroditic duct; *spth.*, spermatheca. x 8.

PLATE IX.

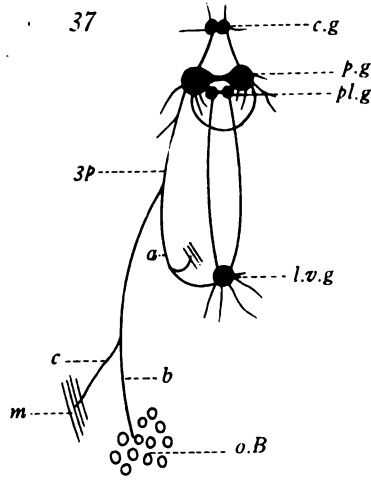
- Fig. 36. Diagram of Central Nervous System of *Tethys punctata* (Cuv.), seen from below, after Mazzarelli.
- Fig. 37. Diagram of Central Nervous System of *Tethys depilans* (Linn), seen from below, after Mazzarelli.
- Fig. 38. Diagram of Central Nervous System of *Tethys dactylomela* (Rang), seen from below.
- Fig. 39. Diagram of Central Nervous System of *Tethys cervina* Dall and Simpson, seen from below.

The following abbreviations apply to all the figures of this plate: *c. g.*, cerebral ganglia; *p. g.*, pedal ganglia; *pl. g.*, pleural ganglia; *l. v. g.*, left visceral ganglion, fused more or less completely with its fellow, the right parietal ganglion; *o. B.*, organ of Bohadsch, or hypobranchial gland; *3p.*, third pedal nerve, *a*, its branch anastomosing with the right parietal ganglion, *b*, its branch to the organ of Bohadsch, *c*, its branch or branches to the muscles of the body wall, *m*, also in figs. 38 and 39 anastomosing with the recurrent branch, *2c*, of the second nerve, *l. v. 2*, from the left visceral ganglion; *2a*, hepatic branch of second visceral nerve, *2b*, its main trunk to siphon and anus.

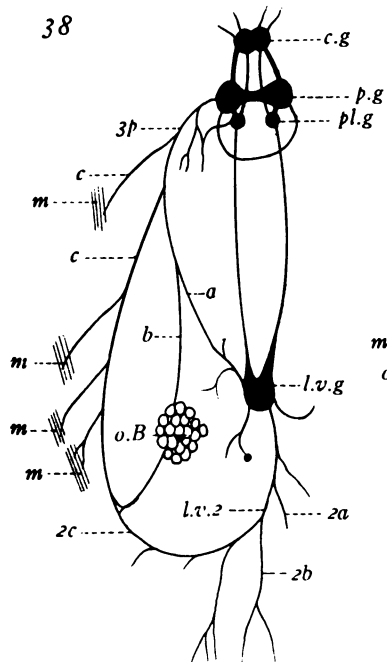
T. punctata (Cuv.)



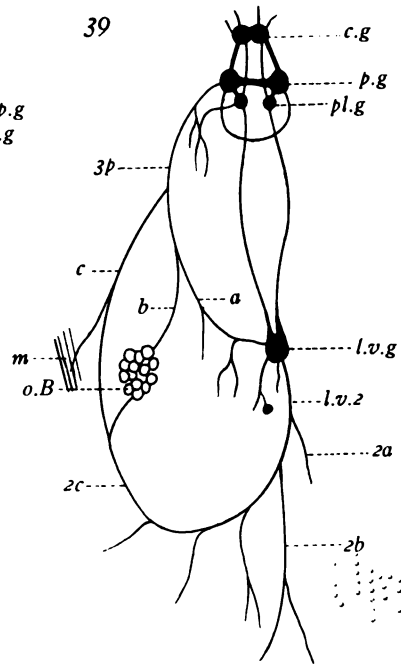
T. depilans (Linn.)



T. dactylomela (Rang)



T. cervina D & S



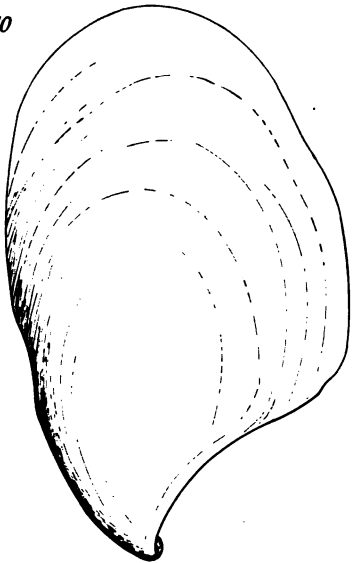
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PLATE X.

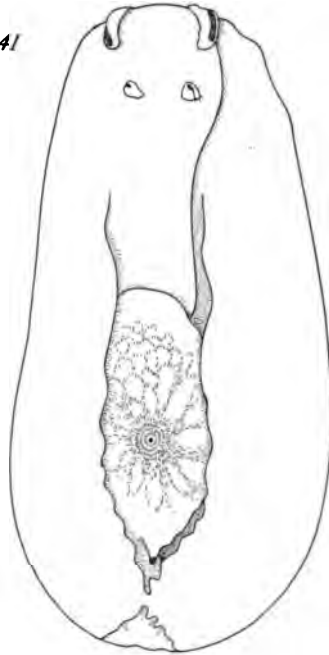
Tethys cervina Dall and Simpson.

- Fig. 40. Dorsal view of shell. x 46.
- Fig. 41. Outline sketch of preserved specimen in dorsal view, mainly intended to show the general proportions and the markings surrounding the mantle pore. Tentacles and rhinophores strongly contracted, the head itself less so. x 2.
- Fig. 42. Detail of parieto-visceral ganglion complex from above, the two fused ganglia being rotated into side view, and all the nerves being more or less displaced to show their mutual relations. *pl. p. con.*, pleuro-parietal connective; *pl. v. con.*, pleuro-visceral connective; *r. p. g.*, right parietal ganglion; *l. v. g.*, left visceral ganglion; *r. p. 1*, vulvar nerve; *r. p. 1a.*, its branch anastomosing with the third pedal nerve; *r. p. 1b.*, its branch to anterior end of large hermaphroditic duct; *r. p. 2*, osphradio-ctenidial nerve; *osp. g.*, osphradial ganglion together with a portion of the integument cut out from the body wall; *ct. g.*, ctenidial ganglion; *osp. g. 1*, nerve to anterior and lateral regions of the mantle; *ct. n.*, main ctenidial nerve; *l. v. 1*, nerve to vesicle of Swammerdam, or spermatocyst, and its duct; *l. v. 2*, *l. v. 3*, *l. v. 4*, second, third and fourth nerves from the left visceral ganglion. x 20.

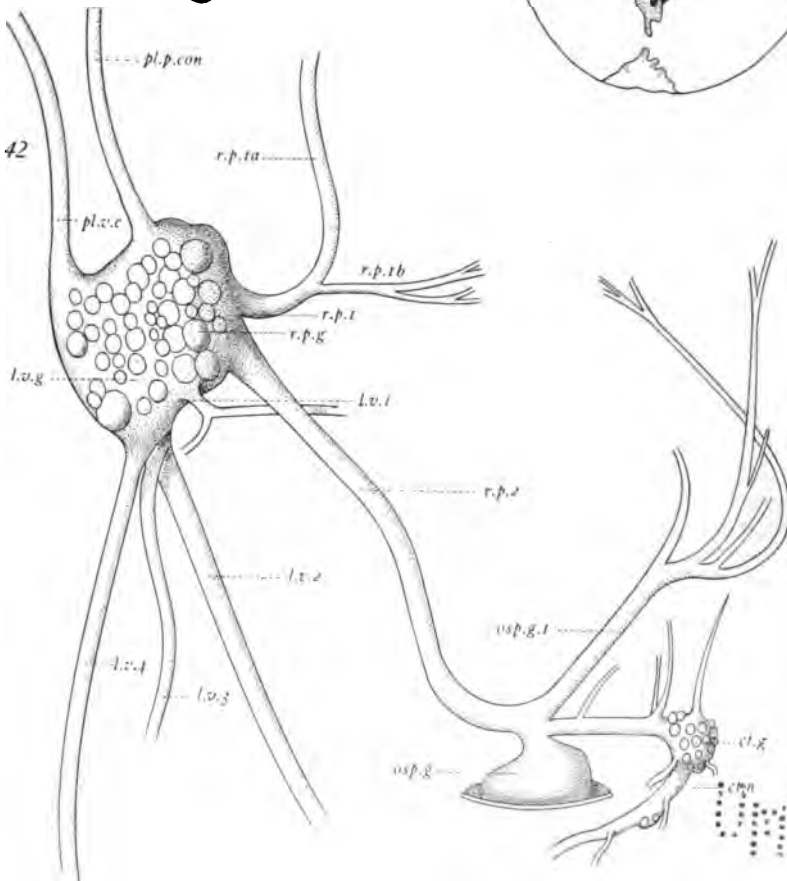
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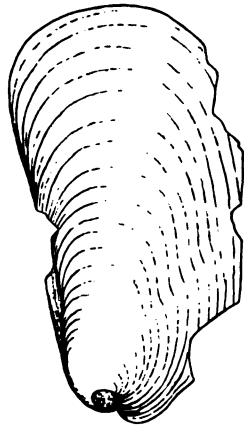


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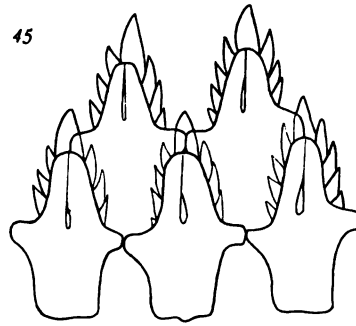
PLATE XI.

Pleurobranchus agassizii MacFarland.

- Fig. 43. Shell in dorsal view. x 15.
- Fig. 44. Dorsal view of 10th, 11th, and 12th elements of labial armature from 8th to 10th rows. x 240.
- Fig. 45. Ventral view of elements of labial armature from near margin of 65th and 66th rows. x 372.
- Fig. 46. Ventral view of bases of elements of labial armature from middle portion. At this focus the hook and denticles are not seen. x 240.
- Figs. 47, 48. Lateral views of isolated elements of labial armature. x 372.
- Fig. 49. Outermost lateral teeth of eleventh row of radula. x 450.
- Fig. 50. Twenty-first and twenty-second lateral teeth of 22d row of radula. x 450.
- Fig. 51. 16th, 17th, and 18th teeth of 19th row of radula, obliquely from above. x 450.
- Fig. 52. 1st, 2nd, and 3rd lateral teeth of 19th row of radula, obliquely from above. x 450.
- Fig. 53. Ventral view of bases of 17th to 21st lateral teeth of 11th row of radula. x 450.
- Fig. 54. Lateral view of glans penis and vaginal opening from below. v., vaginal opening. x 12.



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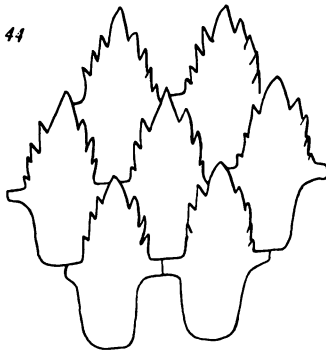


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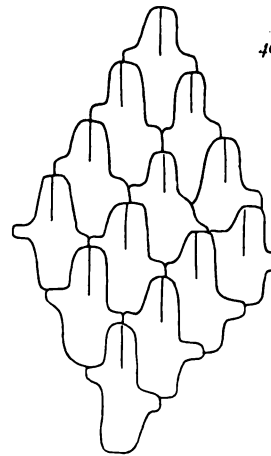
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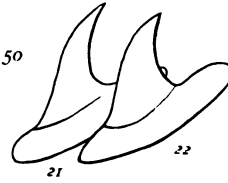
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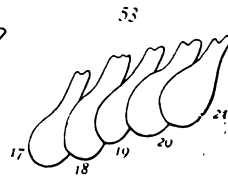
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PLATE XII.

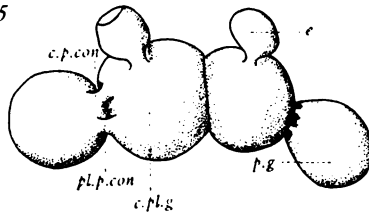
Figs. 55-57. *Pleurobranchus agassizii* MacFarland.

- Fig. 55. Dorsal view of ganglia of Central Nervous System, the nerves and ventral commissures not being represented. *c. pl. g.*, cerebro-pleural ganglion; *p. g.*, pedal ganglion; *c. p. con.*, cerebro-pleural connectives; *pl. p. con.*, pleuro-pedal connectives; *e.*, eye and optic ganglion. x 28.
- Fig. 56. Outline of mandibular armature. *d.*, dorsal margin; *a.*, anterior margin; *v.*, ventral margin. x 28.
- Fig. 57. Ventro-lateral view of right rhinophore. x 12.

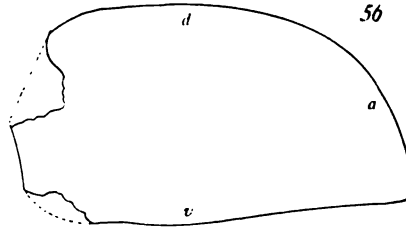
Figs. 58-65. *Discodoris branneri* MacFarland.

- Fig. 58. Mandibular armature. x 30.
- Fig. 59. Anterior rodlets of mandibular armature. x 214.
- Fig. 60. Posterior rodlets of mandibular armature. x 214.
- Fig. 61. Outermost lateral teeth of 16th row of radula in side view. x 120.
- Fig. 62. Outermost lateral teeth of 7th row of radula, in side view. x 120.
- Fig. 63. Typical lateral tooth from 5th row, in side view of inner face. x 214.
- Fig. 64. Hooks of armature of glans penis, *a*, in side view; *b*, in front view. x 214.
- Fig. 65. Reproductive organs from above, the parts slightly displaced so as to show their mutual relations. *h. d.*, hermaphroditic duct; *h. amp.*, hermaphroditic ampulla; *sp. d.*, spermatic duct; *ov. d.*, oviduct; *pr. g.*, prostate gland; *v. d.*, vas deferens; *p.*, glans penis; *n. a. c.*, nidamental-albumen gland complex; *n. d.*, duct of nidamental gland; *u. d.*, uterine duct; *sp. c.*, spermatocyst; *spth.*, spermatheca; *vag.*, vagina, passing over proximally into the vaginal duct, its distal portion laid open by a triangular incision. x 10.

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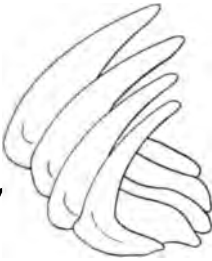
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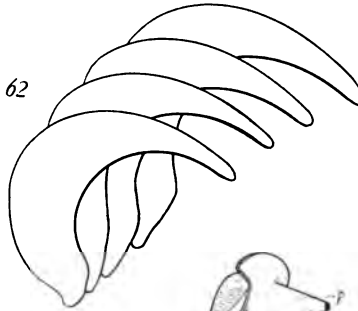
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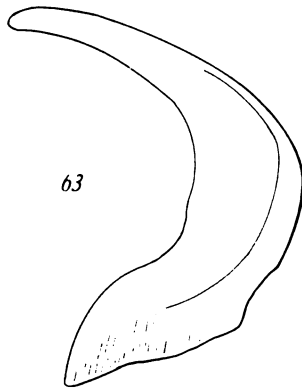
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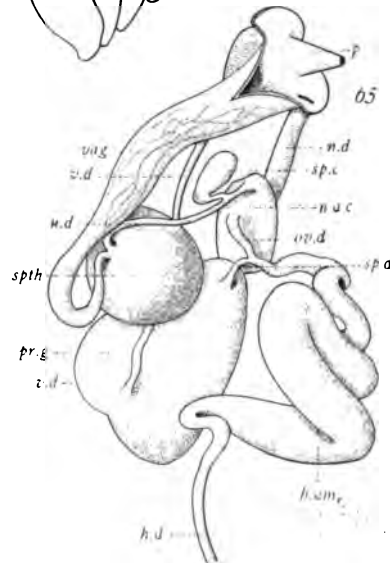
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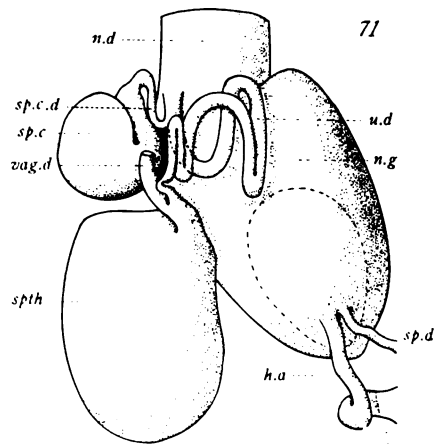
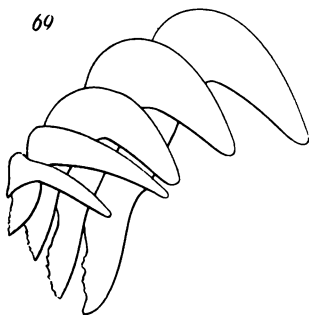
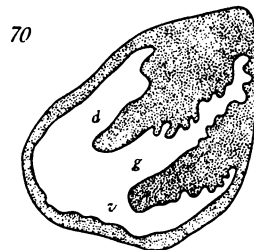
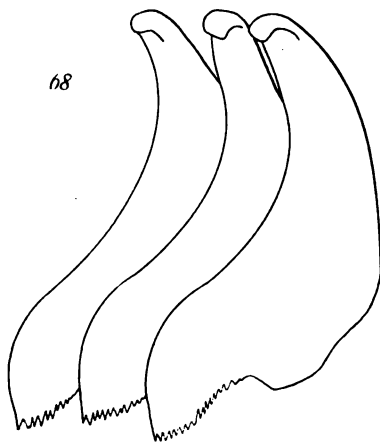
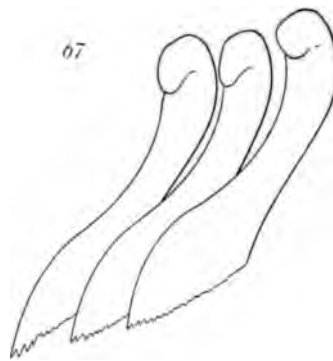
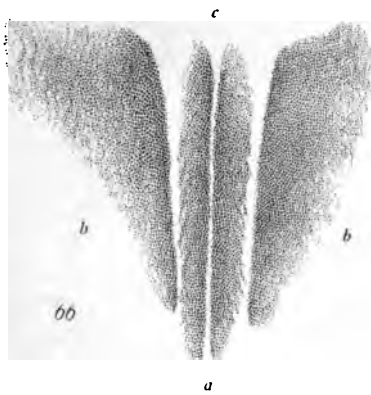


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PLATE XIII.

Discodoris voniheringi MacFarland.

- Fig. 66. Labial armature. *a*, median; *b*, lateral plates; *c*, anterior border. x 37.
- Fig. 67. Front view of three typical lateral teeth of first row of radula. x 212.
- Fig. 68. Front view of three typical lateral teeth from middle of first row of radula. x 212.
- Fig. 69. Outermost lateral teeth of 11th row of radula, obliquely from above. x 212.
- Fig. 70. Outline of cross-section of nidamental duct. *d*, dorsal; *v*, ventral ridge; *g*, groove between them. x 50.
- Fig. 71. Reconstruction from serial sections showing detailed relations of the ducts of the anterior genital mass. *h. a.*, anterior end of hermaphroditic ampulla as it enters the nidamental-albumen gland complex; *sp. d.*, spermatid duct emerging; *n. d.*, nidamental duct; *spth.*, spermatheca; *u. d.*, uterine duct; *sp. c.*, spermatocyst, with its duct, *spc. d.*, leading into the uterine duct; *vag. d.*, vaginal duct, cut off short to show the relations of the underlying organs. The dotted oval upon the surface of the nidamental gland indicates the approximate boundary of the albumen gland.

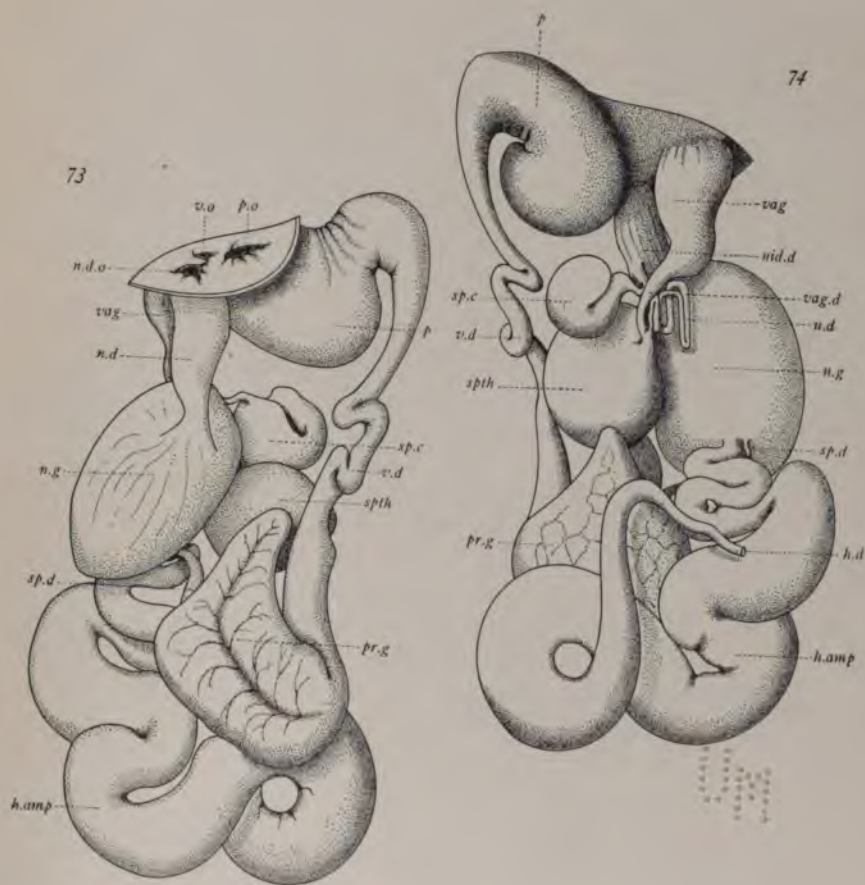
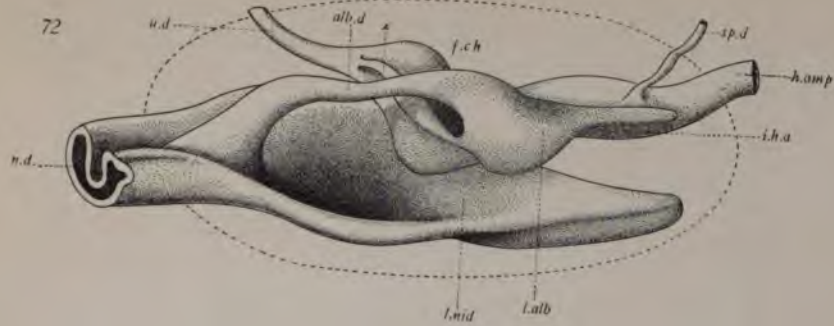


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PLATE XIV.

Discodoris voniheringi MacFarland.

- Fig. 72. Reconstruction from serial sections showing the mutual relations of the principal ducts and cavities within the nidamental-albumen gland complex. The less important branches and all of the secretory alveoli of the glands have been omitted, and are to be thought of as filling the space between the ducts represented and the dotted line, which indicates the external contour of the gland complex, as seen in side view. *h. amp.*, the distal end of the hermaphroditic ampulla as it enters the gland; *i. h. a.*, its intraglandular portion, dilating into *f. ch.*, the fertilization chamber; *u. d.*, uterine duct; *l. alb.*, lumen of albumen gland; *x.*, duct connecting intraglandular portion of hermaphroditic ampulla with the lumen of albumen gland; *alb. d.*, albumen gland duct connecting the albumen gland with the lumen of the nidamental gland; *l. nid.*, lumen of nidamental gland; *n. d.*, nidamental duct, cut across as it leaves the gland. The cut end represents the thickness of the epithelial lining of the duct only. x 165.
- Figs. 73 and 74. Ventral and dorsal views respectively of the reproductive complex. All connective tissue, nerves and blood vessels have been omitted for the sake of clearness. *h. d.*, cut end of hermaphroditic duct; *h. amp.*, hermaphroditic ampulla; *sp. d.*, spermatic duct; *n. g.*, nidamental-albumen gland complex; *nid d.*, nidamental duct; *vag.*, vagina; *vag. d.*, vaginal duct; *u. d.*, uterine duct; *spth.*, spermatheca; *spc.*, spermatocyst; *pr. g.*, prostate gland; *v. d.*, vas deferens; *p.*, penis; *p. o.*, external opening of præputium; *v. o.*, external vaginal opening; *n. d. o.*, external opening of nidamental duct. x 36.



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PLATE XV.

Figs. 75-76. *Discodoris voniheringi* MacFarland.

Fig. 75. Side view of typical lateral tooth from near center of 1st row of radula. x 244.

Fig. 76. Four lateral teeth from inner end of 16th row, slightly displaced. x 244.

Figs. 77-82. *Peltodoris greeleyi* MacFarland.

Fig. 77. Two typical spicules from dorsum. x 244.

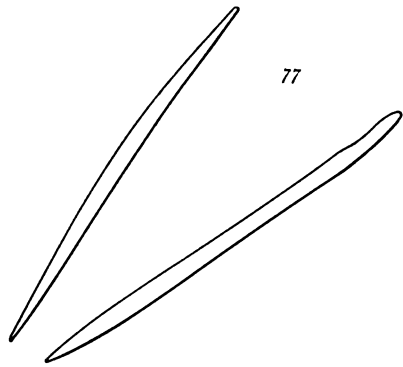
Fig. 78. Oblique view of base of typical lateral tooth of radula. x 282.

Fig. 79. Outermost lateral teeth of 19th and 20th rows of radula. x 244.

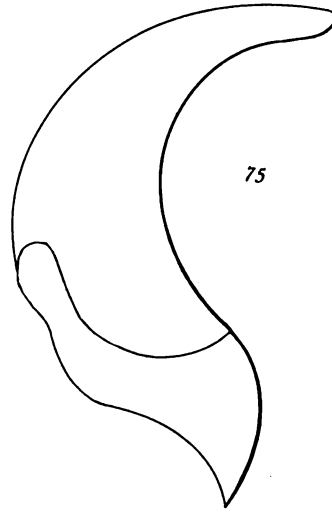
Fig. 80. Innermost lateral teeth of 17th row of radula. x 244.

Fig. 81. Typical lateral tooth of radula in side view. x 282.

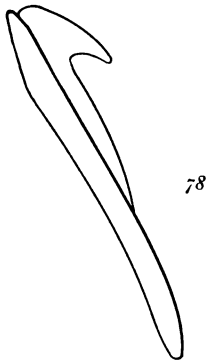
Fig. 82. Portion of anterior genital complex, the nidamental and albumen glands having been removed. *h. d.*, anterior end of hermaphroditic duct; *h. amp.*, hermaphroditic ampulla; *sp. d.*, spermatid duct entering proximal end of large prostate gland, *pr.*; *u. d.*, uterine duct, receiving the duct of the spermatocyst, *spc.*, and cut off just before its entrance into the nidamental gland; *spth.*, spermatheca; *vag. d.*, vaginal duct, its distal portion severed just before it dilates into the vagina; *v. def.*, proximal portion of vas deferens. x 10.



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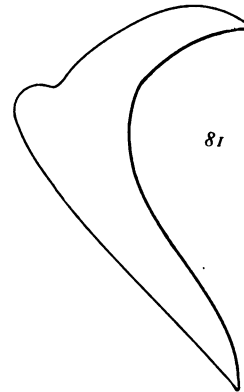
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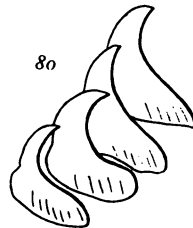
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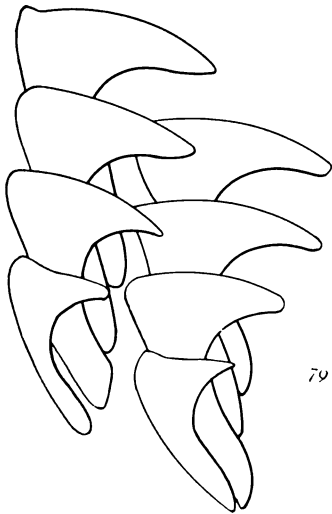
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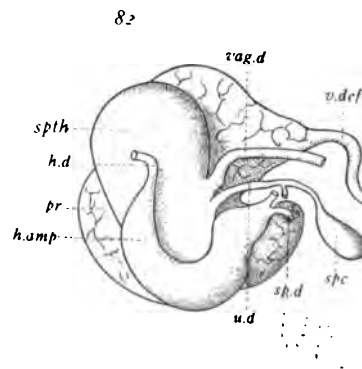
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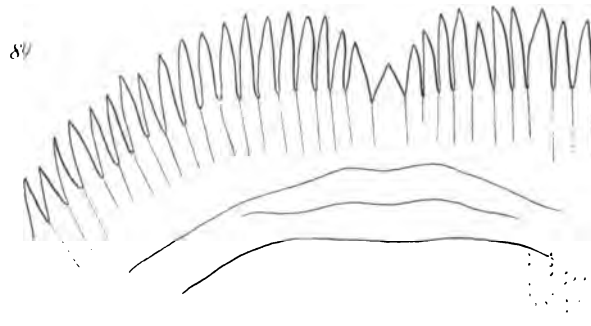
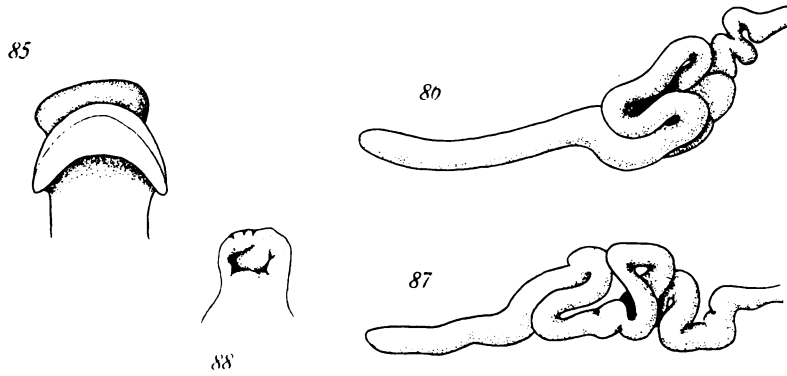
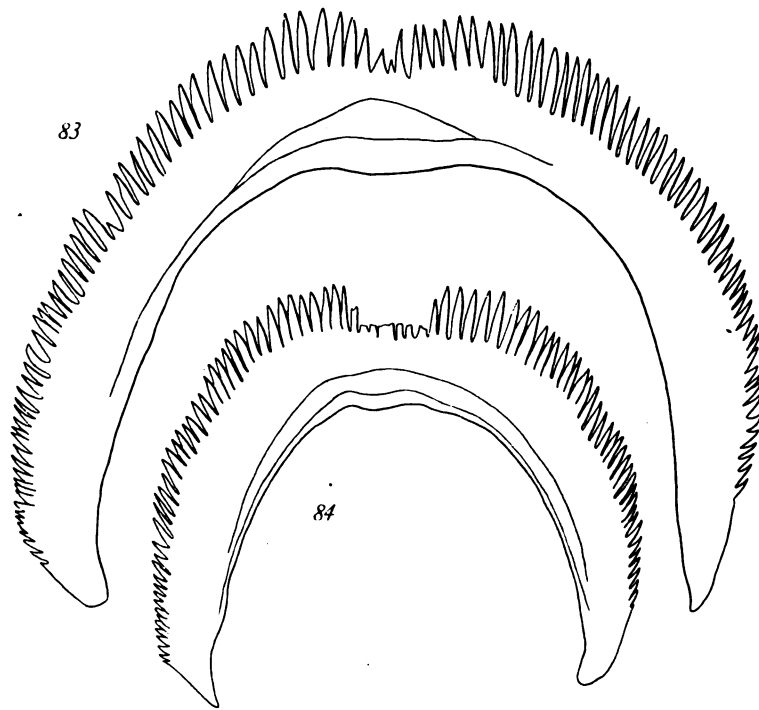
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PLATE XVI.

Spurilla brasiliana MacFarland.

- Fig. 83. Twelfth tooth of radula. x 116.
- Fig. 84. First tooth of radula. x 116.
- Fig. 85. Anterior end of foot in ventral view, the extruded mouth region showing above. x 5.
- Fig. 86. Left salivary gland in side view. x 10.
- Fig. 87. Right salivary gland in side view. x 10.
- Fig. 88. Anal papilla. x 10.
- Fig. 89. Median portion of typical tooth of radula. x 146.



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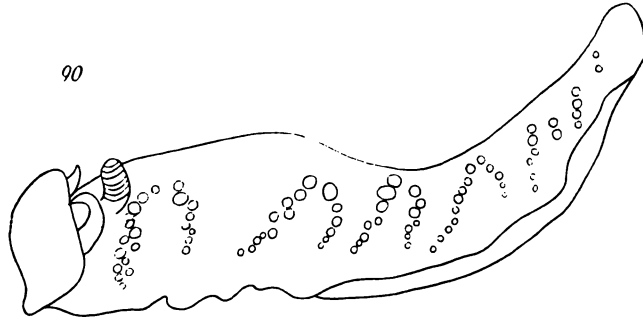
PLATE XVII.

Spurilla brasiliiana MacFarland.

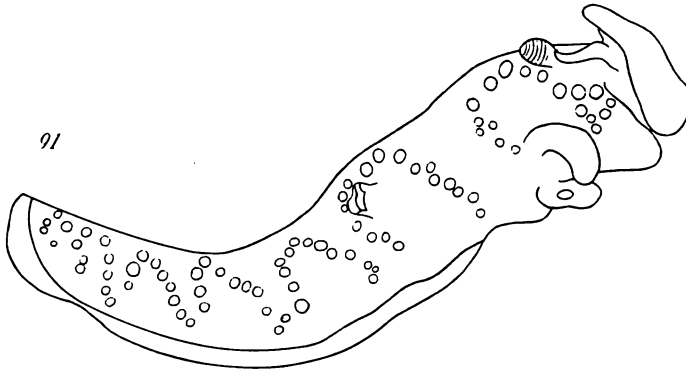
Figs. 90 and 91. Outline sketches of preserved specimen from left and right sides. The dorso-lateral cereta have all been removed, the outline of their bases showing their relative position. The mouth region and reproductive openings are partly everted and much distorted, and the rhinophores are strongly contracted. x 5.

Figs. 92 and 93. Inner surfaces of left and right mandibles. *a.*, superior margin; *b.*, inferior margin; *c.*, posterior tip of masticatory process; *d.*, fulcrum, or hinge, with single crest in left mandible; *e.*, the same, with double crest in right mandible. x 16.

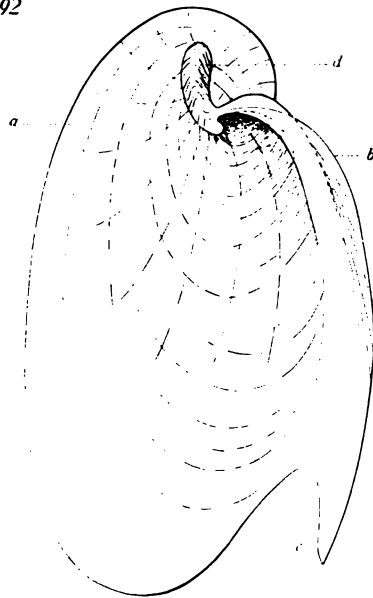
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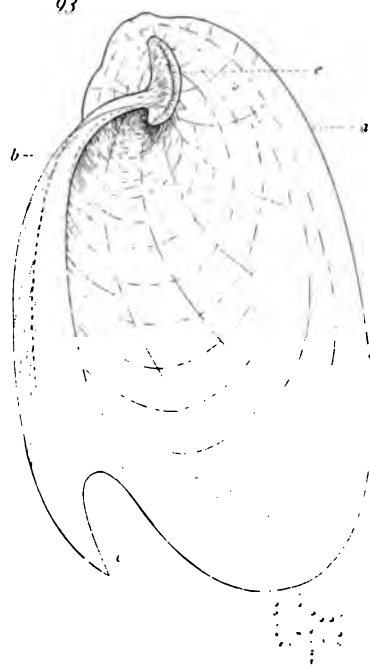
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of the
San Francisco Peninsula

BY

JOHN PEARCE MITCHELL

Assistant Professor of Chemistry
Leland Stanford Junior University

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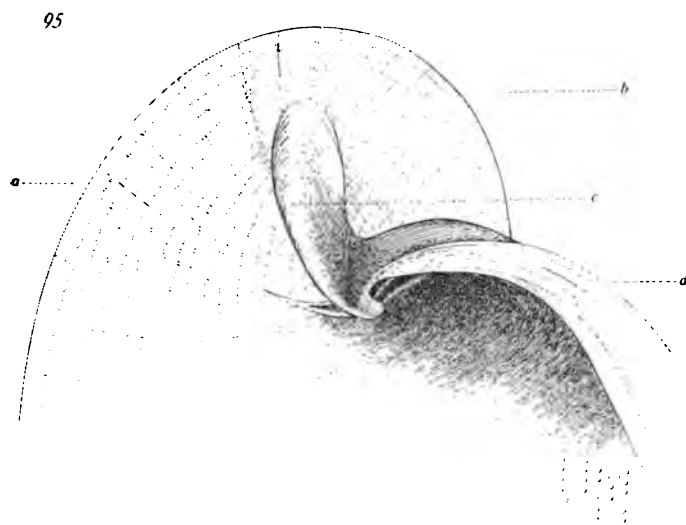
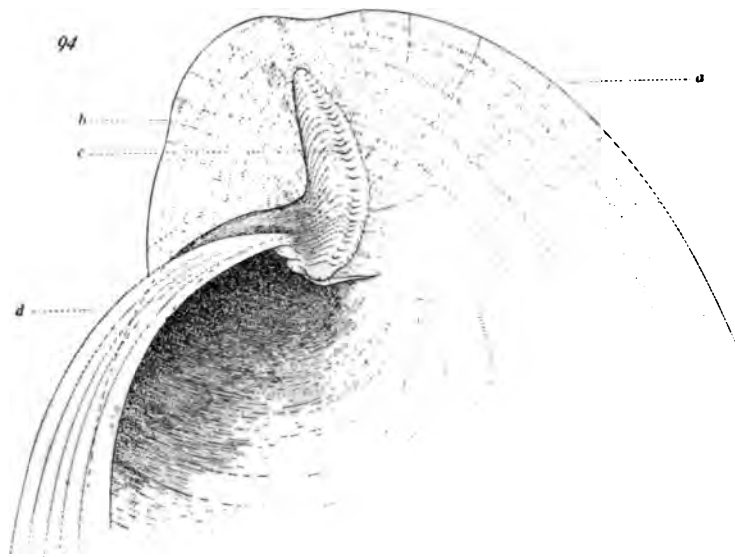
WITH MAP

STANFORD UNIVERSITY, CALIFORNIA
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1910

PLATE XVIII.

Spurilla brasiliiana MacFarland.

- Fig. 94. Detail of head, or hinge region of right mandible, inner surface. *a.*, superior margin; *b.*, inferior margin; *c.*, the fulcrum, bearing double longitudinal crests bounding a longitudinal groove, into which the single crest of the left mandible fits; *d.*, ventral margin of the anterior portion of the masticatory process. x 45.
- Fig. 95. Detail of head region of left mandible, inner surface. Lettering as in preceding figure. The fulcrum, *c.*, bears a single crest. x 45.



The considerations which have been outlined are not by any means restricted to this locality, but apply to the whole country. What has been done here on a small scale, should be done everywhere on a larger scale. In Massachusetts the State Board of Health did similar work for the whole state, and since then it has been done for other of the eastern states. In California nothing of this sort has been done systematically. The need however is just as great, and the opportunity offered by the large supplies of still clearly unpolluted water is greater, and it is to be hoped that the State will undertake the work while the results will still be of the greatest value.

When a water supply is considered chemically with the object of determining its potability, that is from the sanitary, and not from the industrial point of view, two points should be borne in mind. First, that a knowledge of every individual substance in the water is neither required nor possible to obtain. Second, that it is very seldom that the substances determined in the water themselves, but rather the pollution which their presence in abnormal quantities indicates, that renders it unfit for human consumption. In other words the chemical analysis simply indicates, by the abnormal character of the constituents, that a certain water is, or has been, exposed to pollution, and is therefore not safe for use as a drinking water unless the absence of disease carrying bacteria can be demonstrated. Furthermore, if the chemical analysis of a water indicates that it has been exposed to pollution in the past, and the bacteriological examination shows absence of immediate danger, the safety of the supply is in doubt, until such precautions are taken as will guard against infection in the future. It is then of importance to know the content of a water with regard to those particular constituents which signify pollution.

The constituents which are significant have been determined by experience. The most obvious of them is organic matter. No satisfactory method for determining directly the amount present is known, so that a number of indirect methods are in use. First the free ammonia is determined. Ammonia is known to be one of the final products of the decay of nitrogenous organic matter, and an excessive amount of it in a water indicates that such decay is actually taking place. Next the so-called "albuminoid ammonia" is determined. This furnishes a measure of the nitrogenous organic matter, the nitrogen of which is not yet completely converted into ammonia. Then the nitrites and the nitrates are determined. The former are an intermediate step in the oxidation of the organic matter by the "bacteria of nitrification," and their presence indicates this oxidation to be actually in progress; the latter are the final

products of this oxidation, and indicate the amount of organic matter which has been thus oxidized and not yet absorbed as food by living vegetable organisms. Two possible errors must be avoided in the consideration of the significance of the organic matter. One is that its absence may only indicate that it has decayed, been oxidized, and completely absorbed by plants, while the disease carrying bacteria introduced with it are still alive; and the other is that, though present in great quantity, it may be of purely vegetable origin and not necessarily injurious from a sanitary point of view.

Another determination sometimes made is that of the "oxygen consumed." This gives a measure of the amount of potassium permanganate which the water is able to reduce under certain conditions, and the amount is usually approximately proportioned to the "albuminoid ammonia" in the same water. The exact determination of this value is so largely dependent on the conditions under which it is made, and its significance differs so little from that of the "albuminoid ammonia," that it has not been included in this investigation.

A less direct indication of pollution is furnished by the chloride content of the water. Sewage contains large amounts of common salt; this salt is not affected by any of the processes of decay and subsequent oxidation of the organic matter, nor is it absorbed by plants; it is readily soluble, and once introduced is very sure to remain in the water until the latter is evaporated. Hence a very large salt content may indicate that at some time the water has been polluted. There is, however, one important fact which modifies this conclusion, and that is that there is a certain normal chloride content for every water supply. This normal content can be determined for a region, and then any excess of chlorides above the normal is significant. In Massachusetts the State Board of Health found that the normal chloride content varied with the distance from the Atlantic ocean, and was able to draw curves ("iso-chlors") on a map of the state which indicate the normal value in every locality. Similar work has been carried out in other states. The value of a chloride determination depends therefore on a knowledge of the normal value for the locality in question.

The hardness of a water, and the amount of residue left when it is evaporated, are also constituents which are generally determined. The hardness has more industrial than sanitary significance, but, since a drinking water is generally used for laundry purposes, it is a factor which comes within the scope of this investigation. The amount of residue left on evaporation serves as a check on the other determinations, and discloses any abnormal amount of inorganic matter present. Other

less important observations which are made systematically include the odor, color, turbidity, and sediment.

The interpretation of the results of an analysis is made difficult by the absence of any fixed standards of purity. Such factors as character of source, seasonal variation, topography of the region, climate, and the sanitary conditions of the immediate surroundings must all be considered. Thus the local conditions as well as the local standards must be known if the interpretation is to be of value. The furnishing of these local standards and their interpretation with reference to the topography, climatology, and sanitary condition of the locality, have been the main objects of this investigation.

This investigation covers the greater part of the San Francisco peninsula. On the eastern slope the northern boundary is given by a line extending west from Baden, not including the watershed of Lake Merced, and the southern boundary by the watershed between the Guadalupe and Coyote rivers south of San Jose. On the western slope the boundaries are Salt Valley on the north, and the watershed between Pescadero and Butano creeks on the south. The area on the eastern side is about three hundred and eighty-five square miles, on the western two hundred and ninety, making a total of approximately six hundred and seventy-five square miles. The range of mountains which divides the peninsula into the eastern and western slopes varies in height from about six hundred feet at the northern boundary to about twenty-seven hundred feet at the southern. Parallel with this main ridge are numerous similar ridges of varying lengths and elevations. These are all the result of numerous, geologically recent, displacements. The main fault line of the San Francisco earthquake of 1906, traverses the peninsula from north to south in a direction approximately parallel to that of the main ridge. There is very little timber standing on the eastern slope of the mountains, the ground is largely covered with a heavy growth of shrubbery, the foot-hills are pasture lands, or are cultivated, and the floor of the valley is under cultivation as far as the marshes which border the bay. The western slope varies from pasture land at the northern end, to dense forests with a large amount of standing redwood timber near the southern boundary. The soil is largely loose or sandy, with considerable, irregular, beds of clay. On the east the land below the foothills is devoted to the raising of fruit, vegetables, hay and grain, while on the west the portion which is not wooded is used almost exclusively for pasture lands in connection with large dairies. A small strip along the ocean at the northern end of the western area is used for vegetable raising; mostly for artichokes, for which the climate seems peculiarly adapted.

The climate of the peninsula is typical of that of the central and southern California coast. There is a long dry season during the summer months, which is followed by light rains in the autumn, and then, during the winter, by a prolonged period of heavy rainfall. In the Santa Clara valley, that is on the eastern slope, the rainfall increases from San Jose at the southern end to San Francisco at the northern. Thus the mean annual rainfall at San Jose is 14.88 inches,* at Menlo Park 16.43 inches, at San Mateo 20.71 inches, and at San Francisco 23.00 inches. More than half of the annual rainfall occurs during the months of December, January, February and March. Rain during July and August is almost unknown. The annual rainfall, except in San Francisco, is very seldom less than ten inches, or more than twenty. A fair example of a normal year is given by the record obtained at Menlo Park in 1895. The precipitation by months was as follows:

Jan.	Feb.	Mch.	Apl.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
7.12	1.59	2.30	1.44	0.36	0.00	0.00	0.00	0.00	1.16	1.45	1.13	16.55

The wide variation in the rainfall within this comparatively small area is very marked. There are two small areas where the annual rainfall reaches fifty inches, one at Lake Pilarcitos near the northern boundary of the field of investigation, and the other at the head waters of Boulder and San Lorenzo creeks, south of Black Mountain, and just beyond the southern boundary of the field.† At San Mateo, where the peninsula is about ten miles wide, the annual rainfall is twenty inches. Westward it increases to the maximum of fifty inches at Lake Pilarcitos, and drops again to twenty inches at the ocean shore. At Palo Alto the mean annual rainfall is about sixteen inches, at Searsville reservoir, only five miles westward, it is about thirty-five inches. In general the rainfall on the western slope is greater than that on the eastern; and that along the ridge is from two to three times that in the Santa Clara valley. The rainfall for the seasons during which this work was carried out was, for 1906-1907 20.77 inches, and for 1907-1908 12.14 inches at Palo Alto where the mean annual rainfall for twelve years is 15.87 inches.‡ The same relation between the rainfall for these seasons and the average value, which exists at Palo Alto, may be considered to apply throughout

* "Climatology of California," by A. G. McAdie: Bulletin L, U. S. Department of Agriculture, Weather Bureau.

† "Rain and Run-off near San Francisco, California," by C. E. Grunsky: Proc. Am. Soc. of Civil Eng. 34: 339 (April, 1908).

‡ These data were very kindly supplied by Mr. John A. Squire, Displayman U. S. Weather Bureau, at Palo Alto.

the whole region. It will be noted that the season 1906-1907 had a rainfall well above the average, and the season 1907-1908 one somewhat below.

The summer "trade winds" introduce another very important factor. These winds blow from the northwest throughout the summer months, day after day, with great regularity, and with considerable force. One result of this is seen in the very marked bending of the trees in exposed places towards the southeast. Another result is observed in the fog and spray carried off the ocean towards the land. These strong, dry winds, sweeping over an ocean covered with "white caps," and over an almost unbroken line of heavy surf, pick up the spray thrown into the air, evaporate the moisture, and carry the salty residue in the form of an imperceptibly fine dust. This dust is eventually deposited on the ground, particularly in the more exposed places, and adds especially to the chloride content of the neighboring streams.*

The fog conditions throughout the area are also peculiar. The daily "trade winds" during the summer often bring a heavy bank of fog off the ocean towards the land, whose progress is checked by the main ridge of the peninsula, and from which the eastern slope is well protected. Thus the two sides are exposed to very different climatic conditions. The influence of these factors on the normal chloride content of the waters will be considered more in detail after the data collected have been presented.

The population of the area outside of the towns and villages is very small. Most of the towns are located either along the shore of the ocean or of the bay. An estimate of the population in the mountainous part, that is on the watersheds of the streams, indicates that it does not exceed eight per square mile. This is an average value, for a large number of the watersheds are totally uninhabited.

This study has been confined almost entirely to surface waters; that is to streams, springs and catchment reservoirs. Some work has been done on the wells, but they have not been covered at all thoroughly as they belong in a class by themselves which it is planned to consider in a separate investigation. The great majority of the wells in this area are located on the floor of the valley in the southeastern region. In the foothills on the eastern slope there are some wells sunk near the beds of the streams, to tap the underground flow, but most of the inhabitants depend upon streams, springs, and catchment reservoirs. On the western

*The large amounts of salt which may be transported in this way have been mentioned by E. Dubois: *Haarlem. Arch. Mus. Teyler* (2) 10, IV: 461 [Chemical Abstracts 1907: 1528].

side of the mountains there are almost no wells except in the small towns close to the ocean where there are no available streams or springs.

The constituents of normal water supplies which are most significant from the sanitary point of view have been determined. These are the free and "albuminoid" ammonia, nitrites, nitrates, chlorides, hardness,—permanent and temporary,—total solids, change of residue on ignition, color, odor—in both the cold and the heated sample—turbidity, and sediment. In a number of cases the chlorides only were determined.

The waters examined have been classified with reference to their probable purity as determined by the author by a study of the topography of the neighborhood, and of the location of possible sources of pollution. The purposes of this investigation exclude at once all waters known to be polluted, and every effort was made to collect samples of the purest water obtainable. A few polluted waters were examined for the sake of comparing them with the unpolluted. The following classification is based entirely on the evidence obtained in the field, and is independent of the analysis.

Class A comprises waters of unquestionable purity.

Class B comprises those for which it was determined that a possible source of pollution was so remote as to be negligible.

Class C comprises those perhaps slightly polluted, but not sufficiently so to affect materially the analytical data.

Class D comprises those probably polluted sufficiently to have some effect on the analytical data.

Classes A and B are comparable, for all waters not clearly in the first class were graded "C" until evidence was obtained to prove that any possible source of pollution could, at that time, be neglected.

The samples were all collected by the writer personally and according to the directions given by the Massachusetts State Board of Health.* Glass-stoppered bottles of about two and a half liters capacity were used. Before use the bottles were rinsed thoroughly with dilute sulphuric acid, five times with distilled water, and, since the distilled water contained considerable free ammonia, twice with ammonia free water. The stopper was covered with two thicknesses of clean filter paper, then with a heavy cotton cloth, and the whole tied firmly into place. When the sample was collected the covering, which had been protected from dirt, was replaced. In the laboratory the covering was removed, the bottle washed off with distilled water, placed on its side with the mouth over a

* Ann. Rep. St. B. of H., 1890, pp. 520.

sink, the stopper removed, and the bottle rolled along the desk until the contents had rinsed the mouth thoroughly on all sides. The stopper was rinsed at the same time, replaced, and covered with a clean beaker.

When taking the sample the bottle was rinsed three times, filled and emptied once, and then filled with the exception of a small air space. The stopper was rinsed thoroughly in the water being sampled. The sample from streams was taken either below the surface in a pool, or, where the flow was too small, from a place where the water was running rapidly over a stone. If the stream was very small the sample was taken from a small waterfall in preference to using a dipper. The mouth of the bottle was kept below the surface and above the bottom, and was always pointed upstream away from the collector. As far as the roads permitted every stream was followed to its source, and no stream was classed as "A" unless its source had been thus inspected, or its watershed was known to be entirely uninhabited. The samples from springs were taken from below the surface of the pool, and the rinsings were poured well to one side. In ponds and reservoirs the bottle was held eight to twelve inches below the surface,—the latter distance whenever possible. The nitrogen content of the sample was always determined within forty-eight hours of the time of collection, and generally within twenty-four.

The chemical analyses were made by the writer personally according to the standard methods in general use. It was known from previous experience that the waters in the region contained large amounts of chlorides, and, since the usual phenol sulphonic acid method for determining nitrates was known to be affected by such conditions, a special study of the methods for determining nitrates was undertaken.

Certain of the physical characteristics of the waters were determined in the following manner.

The turbidity of the water was considered to be due to the solid matter remaining in suspension after the sample had stood for twelve hours in the laboratory. The solid matter which settled to the bottom of the bottle during that time was considered to be the sediment. Neither the turbidity nor the sediment were determined quantitatively. The degree of turbidity was expressed by the terms * "very slight," "slight," "distinct," and "decided;" and the amount of sediment by the terms "very slight," "slight," "considerable," and "heavy." As a matter of fact the great majority of the samples examined were free from any turbidity, and contained only a very slight sediment.

The color of the waters examined was not expressed with reference

* cf. "Air, Water and Food," Richards and Woodman, 1906 ed., 133.

to any standard, but was described as "brownish" or "yellowish" in the few cases where any appreciable tint could be detected.

The odor was determined for every sample before and after heating. The first test was made on the portion of the sample, about five hundred cubic centimeters, remaining in the sampling bottle after the other determinations had been made. The bottle was shaken thoroughly, the stopper removed and the odor determined at once. A beaker of about two hundred cubic centimeters capacity was then filled a third full of the water, covered with a well-fitting watch glass, and heated rapidly over a large burner. Just before the water boiled the beaker was put on the desk and allowed to cool for five minutes. The contents were then shaken with a rotary motion, and the nose put well into the beaker.* The different odors were described as "earthy," "vegetable," "musty," "mouldy," and "fishy," and their intensity as "very faint," "faint," "distinct," and "decided."

THE DETERMINATION OF THE NITROGEN PRESENT AS FREE AND "ALBUMINOID" AMMONIA.

The first determinations made were those of the free and the "albuminoid" ammonia. The standard solutions and reagents were prepared according to the directions given by Richards and Woodman.† Distilling flasks of about two liters capacity, and condensers with water jackets from ninety to a hundred centimeters long were used. The method of procedure was to boil some water in a still, until fifty cubic centimeters of the distillate gave no color with the Nessler solution. A measured quantity, with few exceptions five hundred cubic centimeters, of the water under examination was then put in the flask, and the distillate collected in fifty cubic centimeter portions in Nessler tubes until the last portion was ammonia free. This gave the free ammonia. As the waters of the region were all strongly alkaline it was not necessary to add sodium carbonate to the distilling flask. Another portion of the water was put into an ammonia free still containing the alkaline potassium permanganate solution, and the distillate collected until the last portion was ammonia free. This gave the total ammonia. The difference between the total ammonia and the free ammonia gave the "albuminoid" ammonia. Usually five fifty cubic centimeter portions of the distillate were required for the free ammonia determination, and seven for the total.

* cf. Richards and Woodman, loc. cit., 130-131.

†loc. cit.

THE DETERMINATION OF THE NITROGEN PRESENT AS NITRITE.

This determination was carried out by the regular method using sulphanilic acid and α -naphthylamine in acetic acid solutions. A blank determination on the distilled water used for rinsing was made with each set of determinations. One hundred cubic centimeter samples in Nessler tubes were used, and the tubes were allowed to stand in hot water for twenty minutes before comparing the colors.

THE DETERMINATION OF NITROGEN PRESENT AS NITRATE.

The problem of the determination of the nitrogen which is present in a water in the form of a nitrate is one for the solution of which many methods have been suggested. Among them may be mentioned those of Schloesing,* Schloesing-Reichardt,† Schulz-Tiemann,‡ Crum-Lunge,§ Marx-Trommsdorff,|| Dewarda,¶ Busch** and Noll.††

All of these, however, apply only to the determination of relatively large amounts of nitrogen, and generally require the concentration of a rather large volume of water. This concentration is in itself objectionable, partly on account of the changes which may take place in the water during the concentration, ‡‡ partly on account of the resulting delay, preventing the prompt analysis of the water, and lastly on account of the large sample which must be collected. Moreover many of the methods are tedious or complicated, and not at all suited for the routine analysis of a large number of samples.

There are, however, two methods which are not open to the above objections, and which have been extensively used for water analyses. They are known as the "Phenol-sulphonic acid" and the "Reduction" methods.

The Phenol-sulphonic acid method originated with Sprengel §§ and

*J. f. pr. Chem. 62: 142 (1854).

†Zeit. anal. Chem. 9: 24 (1870).

‡Berl. Ber. 6: 1041 (1873).

§Phil. Mag. 30: 426. J. Chem. Soc. 21: 101. Berl. Ber. 11: 434.

||Zeit. anal. Chem. 7: 412; 8: 364; 9: 171.

¶Zeit. f. angew. Chem. 33: 113.

**Berl. Ber. 38: 861, 856, 4055.

††Zeit. angew. Chem. 1901: 1316.

‡‡cf. Tidy, J. Chem. Soc. 35, 53, 97, and A. H. Gill, J. Am. Chem. Soc. 16: 123 (1894).

§§Pogg. Anal. 121, 188 (1864).

has been modified and investigated by Grandval and Lajoux,† Fox,‡ Johnson,§ Lindo,|| Rideal,¶ Smith,** Bartram,†† Hazen and Clark,‡‡ Gill,§§ and Andrews.||||

This method depends upon the formation of nitro-phenols by the action of phenol sulphonic acid on the nitrates left in the residue obtained by the evaporation of a known amount of the water under examination. The nitro phenols |||| formed are measured quantitatively by a colorimetric method based on the yellow color of the ammonium salts formed in the presence of an excess of ammonium hydroxide. It is well known that the presence of chlorides interferes with the accuracy of this method, and as the waters of the region covered in this investigation all contain large amounts of chlorides, it seemed essential to determine what results could be obtained by its application.

The details of the procedure adopted are as follows: Ten cubic centimeters of the water to be examined are measured with a pipette into a small, flat-bottomed evaporating dish placed on a water bath. The bath is so arranged that the dishes set well down into the steam.* The progress of the evaporation is watched; when less than one cubic centimeter is left, the dish is lifted with a pair of tongs and tipped about until the remaining liquid has wet the whole bottom of the dish; this is repeated frequently, and the last drop is evaporated in this way, and never on the water bath. If by oversight a determination is allowed to run to complete dryness on the water bath, it is rejected. When the residue is obtained, it is treated immediately with the required amount of the phenol sulphonic acid, the acid spread over the whole of the residue quickly by means of a small glass rod, and the dish set aside to cool. The contents are then diluted with water, rinsed into a Nessler tube, an excess of ammonium hydroxide is added. The volume is made up to 50 cubic centimeters with distilled water, and the color obtained compared with that of standard solutions.

The phenol sulphonic acid was prepared according to the directions

† *Compte Rendue* 101: 62.

‡ *Tech. Quart.* 1: 54 (1887).

§ *Chem. News* 61: 15 (1890).

|| *Chem. News* 58: 1, 15, 28 (1888).

¶ *Chem. News* 60: 261 (1889).

** *Analyst* 10: 199 (1885).

†† *Journ. Frank. Inst.*, March 17, 1891, referred to by Gill, *J. Am. Chem. Soc.* 16: 123.

‡‡ *J. Anal. Appl. Chem.* 5: 1, referred to by Gill, loc. cit.

§§ *J. Am. Chem. Soc.* 16: 122, 193.

|||| *J. Am. Chem. Soc.* 26: 388 (1904).

* A. H. Gill, *J. Am. Chem. Soc.* 16: 130 (1894).

given by Richards and Woodman;* phenol and pure concentrated sulphuric acid were mixed in the proportion of 3 g. of phenol to 37 g. of acid, and heated for six hours in a boiling water bath. A nearly colorless product was obtained.

Two standards were used. One was prepared by evaporating to dryness ten cubic centimeters of a solution of potassium nitrate containing 0.722 gram in one liter, using all the precautions above described, treating the residue with fifteen cubic centimeters of phenol sulphonic acid, and diluting to one liter. The strength of the solution was such that one cubic centimeter corresponded to 0.000001 gram of nitrogen present as nitrate. The second standard solution was prepared in the same way, but was ten times as strong. These solutions were used in all experiments on the various modifications of the method, so that all the results are expressed in terms of the same standards. They were found to give the same results a year after they were made up. The color given by the addition of ammonium hydroxide to ten cubic centimeters of the first solution, corresponded with that obtained with one cubic centimeter of the second solution.

The first experiment undertaken was to determine whether the color obtained by the evaporation of ten cubic centimeters of a solution containing a known amount of potassium nitrate, was the same as that of a corresponding amount of the standard solutions made as above. For this purpose a series of solutions containing known amounts of potassium nitrate were prepared, ten cubic centimeters of each evaporated and treated as has been described, and the color obtained read in terms of the standard solutions. The results obtained are given in Table I.

Observation of the standard solutions showed moreover that they kept their color without fading appreciably for two days.

The next experiments were designed to determine the influence of certain factors in the process of evaporation and treatment of the residues; namely the completeness of the evaporation, the interval between the removal of the dish from the water bath and the addition of the phenol sulphonic acid, the amount of phenol sulphonic acid added, the heating of the dishes after adding the acid, and the interval between the addition of the acid and the dilution with distilled water.

It was observed that in every case where one of two duplicate determinations was allowed to run to complete dryness on the water bath, loss of nitrogen resulted. Thus in one case two duplicate determinations on a solution containing 0.75 parts per million of nitrogen were made; one

* Richards and Woodman: *Air, Water and Food*, 2d ed., 241.

TABLE I.—TEST OF STANDARD SOLUTIONS.

Amount of N as KNO ₃ in 10cc of solutions evaporated separately, expressed in parts per million	Feb. 2, 1907 Reading obtained in terms of standard solutions	Feb. 4, 1907 Repeated and obtained	Feb. 5, 1907 Repeated	Feb. 5, 1907 Repeated
0.01	0.01(?)	0.01(?)	....
0.01	0.01(?)	....	....
0.05	0.05	0.05	....
0.05	0.04	0.04	....
0.10	0.08	0.09	....
0.10	0.09	0.09	....
0.25	0.24	0.25	....
0.25	0.23	....	....
0.50	0.49	0.49	....
0.50	0.49	0.49	....
0.75	0.60	0.70	0.74	
0.75	0.60	....	....
1.00	0.85	1.00	0.85	1.00
1.00	0.85	0.98	0.95	1.00
3.00	....	....	....	3.00
3.00	....	....	....	3.00
5.00	....	....	....	4.80
5.00	....	....	....	4.80

was allowed to evaporate completely and gave a reading by the standard solutions of 0.60, the other gave 0.70.*

A tendency toward loss of nitrogen was observed if the dishes were allowed to cool after being removed from the water bath and before adding the phenol sulphonic acid. This is illustrated by the following set of parallel determinations:

* cf. A. H. Gill, J. Am. Chem. Soc. 16: 130 (1894).

TABLE II. EFFECT OF COOLING BEFORE ADDITION OF ACID.

Phenol Sulphonic Acid added immediately on removal from water bath	Dishes allowed to cool after removal from water bath and before addition of acid
faint tinge faint tinge	blank blank
0.04 0.03	0.02 0.01
0.04 0.06	0.05 0.02
0.27 0.20	0.17 0.12
0.47 0.57	0.35 0.33
2.50 2.20	1.60
3.50 4.00	3.00 3.50

Preliminary experiments indicated that loss of nitrogen could be prevented by the use of larger amounts of phenol sulphonic acid, but also that the color due to large amounts of the acid interfered with the delicacy of the method. This is shown in Table III. The tubes were compared with known amounts of the standard solutions, and the results expressed in parts per million. In order to reproduce more nearly the conditions existing in the case of an actual water analysis, known amounts of salt were also added to the solutions before evaporation.

From the data it will be seen that the use of as much as 3.5 cubic centimeters of the acid destroys the delicacy of the reaction, no color below that due to 0.10 parts per million of N could be read on account of the color due to the acid itself, and at the same time the results on the larger amounts are no better than those obtained with 1.5 cubic centimeters of acid. On the other hand the use of 1.5 cubic centimeters of acid gave better results than were obtained with ten drops of acid. Therefore, approximately 1.5 cubic centimeters was used in all the following experiments. When the ammonium hydroxide was added to this amount of acid the heat liberated was sufficient to raise the temperature appreciably,

TABLE III.—EFFECT OF AMOUNT OF PHENOL SULPHONIC ACID.

Parts per million of Nitrogen taken	10 drops P. S. acid 10 parts per mill. Cl.	3.5 cc P. S. acid 10 parts per mill. Cl.	10 drops P. S. acid 30 parts per mill. Cl.	1.5 cc P. S. acid 30 parts per mill. Cl.	3.5 cc P. S. acid 30 parts per mill. Cl.	3.5 cc P. S. acid 30 parts per mill. Cl.
0.01	tinge	....	tinge	tinge	2/14/07	2/16/07
0.01	tinge	....	tinge	....	....	....
0.05	0.05	....	0.04	0.03	....	....
0.05	0.05	....	0.03	0.05	....	....
0.10	0.08	0.10	0.04	0.06	0.10	0.10
0.10	0.08	0.10	0.06	0.06	0.10	0.10
0.50	0.30	0.40	0.27	0.30	0.35	0.40
0.50	0.32	0.45	0.20	0.35	0.40	....
1.00	0.75	0.90	0.47	0.90	0.80	0.85
1.00	....	0.85	0.57	0.85	0.85	0.80
3.00	3.00	3.00	2.50	2.30	2.00	2.00
3.00	....	3.00	2.20	2.30	2.70	2.70
5.00	4.50	4.70	3.50	3.70	4.50	4.00
5.00	4.70	4.70	4.00	4.00	4.50	4.00

and time for cooling was allowed before comparing the color with that of the standard solutions.

The heating of the dishes after the addition of the acid and before dilution was found to have no appreciable effect on the results. The data obtained are given in Table IV.

In the course of the work it was observed that those dishes which were allowed to stand a few minutes after the addition of the acid, and before dilution with water, tended to give higher results than did those where the acid was diluted at once. In the subsequent work the dishes were always set aside for a few minutes before the water was added.

The next point taken up was the interference of chlorides with the accuracy of the method. Determinations in solutions containing known nitrate and chloride content were carried out, the colors obtained being compared with those of the standard solutions as before. The data are given in Table V.

TABLE IV.—EFFECT OF HEAT AFTER ADDITION OF ACID.

Parts per million of N taken	1.5 cc of P. S. acid 30 parts per mill. Cl.	1.5 cc of P. S. acid. 30 parts per mill. of Cl. Dishes left on water bath 5 min. after addition of acid
0.01	tinge	tinge
0.01	....	tinge
0.05	0.03	0.03
0.05	0.05	0.02
0.10	0.06	0.06
0.10	0.06	0.05
0.50	0.30	0.35
0.50	0.35	0.30
1.00	0.90	0.70
1.00	0.85	0.80
3.00	2.30	2.70
3.00	2.30	
5.00	3.70	3.50
5.00	4.00	4.00

For quantities of nitrogen of one part per million or less the loss with 80 parts per million chloride is seen to be over 50 per cent. With higher nitrogen content the relative loss is less. With 30 parts per million of chloride the loss is about 30 per cent for quantities of nitrogen below one part per million, and still less above. With 10 parts per million chloride the loss is much smaller. It should be noted that the addition of such a large amount of chloride puts the method to a very severe test, but this is justified by the large chloride content of the waters of the region under examination.*

In actual analyses this loss of nitrogen due to the presence of chlorides might be overcome by using standard solutions prepared by adding known amounts of chloride to them before evaporation and treatment with phenol sulphonic acid. A solution was prepared in this way, exactly like the stronger of the two standard solutions described, except that an amount of sodium chloride corresponding to 30 parts per million was

* cf. Gill, loc. cit.

TABLE V.—EFFECT OF INCREASING CONCENTRATION OF CHLORIDES.

Amt. of P.S. acid	1.7 cc	1.7 cc	1.7 cc	1.7 cc
Parts per mill. of Cl.	0	10	30	80
Amount of N as Nitrate in solutions taken in parts per million				
0.01	tinge	tinge	tinge	tinge
0.01	tinge	tinge	tinge	tinge
0.05	0.04	0.04	0.03	0.02
0.05	0.05	0.04	0.02	0.02
0.10	0.09	0.09	0.06	0.05
0.10	0.09	0.08	0.05	0.05
0.50	0.45	0.30	0.30	0.20
0.50	0.45	0.30	0.25	0.20
1.00	0.90	0.75	0.60	0.55
1.00	0.90	0.60	0.60	0.50
3.00	3.00	2.50	2.50	2.00
3.00	3.00	2.70	2.50	1.00
5.00	5.00	4.50	4.00	3.50
5.00	5.00	4.50	4.50	3.50

added to the potassium nitrate solution before evaporation. In this case a well water containing about 30 parts per million chlorides and a small amount of nitrate was taken, and known amounts of potassium nitrate solution were added. The solutions obtained were compared with the standard made as above described, and also with the one used in the previous work. Three independent series were obtained; in the last two the amount of nitrate was measured by both the old and the new standard solutions. The data are given in Tables VI and VII.

All results are expressed in parts per million of nitrogen present as nitrate. In each series duplicate determinations were made at each concentration.

TABLE VI.—RESULTS WITH STANDARD NOT CONTAINING CHLORIDES.

Amount of KNO ₃ added	VALUES OBTAINED WITH OLD STANDARD SOLUTION								
	First Series			Second Series			Third Series		
	Read- ings	Avg.	Diff.	Read- ings	Avg.	Diff.	Read- ings	Avg.	Diff.
none	0.4 0.3	0.35	....	0.3 0.2	0.25	....	0.4 0.4	0.4	....
0.5	0.7 0.6	0.65	0.30	0.5 0.6	0.55	0.30	0.70 0.70	0.70	0.30
1.0	0.8 0.7	0.75	0.40	0.8 0.85	0.825	0.575	0.9 0.9	0.90	0.50
5.0	4.0 4.0	4.0	3.65	3.8 3.6	3.7	3.45	4.0 4.0	4.0	3.60
20.0	16.8 16.8	16.8	16.45	16.8 16.8	16.8	16.55	18.4 18.4	18.40	18.0
50.0	48.0 46.4	47.2	46.85	46.4 46.4	46.4	46.15	48.0 48.0	48.00	47.60

The above data show, first, satisfactory agreement between the duplicates at each concentration. It was observed that, while with solutions of potassium nitrate in distilled water, especially when some chloride was also added, widely varying duplicates were sometimes obtained, with samples of natural waters the agreement was much better. Second, higher results were obtained with the new standard solution. Third, the agreement between the three independent series is fairly close. In the case of the stronger solutions the color produced was much too dark to be compared with the standards directly. In this case the solution was made up to 100 cubic centimeters with distilled water, thoroughly mixed by pouring back and forth between two Nessler tubes, and finally evenly divided between the tubes. That the division was equal was determined by comparing the color of the two tubes. This was repeated as often as necessary. In the case of the solution containing fifty parts per million of nitrogen the actual comparison was made in a tube containing one-sixteenth of the original solution. In this case this method of procedure

TABLE VII.—RESULTS WITH STANDARDS CONTAINING CHLORIDES.

VALUES OBTAINED WITH NEW STANDARD SOLUTION					
Second Series			Third Series		
Readings	Avg.	Diff.	Readings	Avg.	Diff.
0.4 0.3	0.35	.....	0.4 0.4	0.40	.....
0.6 0.7	0.65	0.30	0.80 0.80	0.80	0.40
0.9 0.95	0.925	0.575	1.0 1.0	1.0	0.60
4.4 4.2	4.3	3.95	4.6 4.6	4.6	4.20
18.4 18.4	18.4	18.05	19.2 19.2	19.2	18.80
49.6 49.6	49.6	49.25	52.8 52.8	52.8	52.40

gave better results than that obtained by using a smaller amount of water, as is shown by the following data:

TABLE VIII.

Evaporation of 10 cc gave :

16.8
16.8

46.0
46.4

Evaporation of 1 cc gave :

15.5
15.5

44.0
44.0

Mason* recommends that instead of using a standard solution as has been described, each standard comparison tube be prepared separately by the evaporation of known amounts of a standard potassium nitrate solution, to which an amount of sodium chloride corresponding to the chloride content of the water, as determined by

* Chemical Examination of Water, 3d ed., pp. 50-51. Jour. Am. Chem. Soc. 16:72 (1894).

previous analysis, has been added. This method was tried, and data obtained as shown in the following tables. In this case duplicates of each concentration of the water, to which known amounts of the nitrate solution had been added, were evaporated and treated in the regular way. The colors obtained were compared, first, with those of known amounts of the standard solution used in all the previous work, second with those of known amounts of the new standard solution to which thirty parts per million of chloride had been added, and, third, to those obtained by evaporating known amounts of the standard potassium nitrate solution, to which chloride corresponding to thirty parts per million had been added, and evaporated separately according to Mason's method. In this way standard tubes corresponding to concentrations of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.4, 2.0, 2.3, 2.5 parts per million were prepared. In every case 10 cubic centimeters of the water was used. The first and second columns of this table are the same as those of the "third series" in the last table. The figures all refer to parts per million.

TABLE IX.—COMPARISON OF RESULTS WITH THREE DIFFERENTLY PREPARED STANDARDS.

Amount of KNO ₃ added	I. Original Standard Solution			II. New Standard Solution with Chloride Added			III. Separate Evaporation of Standard Mason's Method		
	Readings	Avg.	Diff.	Readings	Avg.	Diff.	Readings	Avg.	Diff.
none	0.4 0.4	0.4	....	0.4 0.4	0.40	....	0.45 0.45	0.45	....
0.5	0.7 0.7	0.7	0.30	0.8 0.8	0.80	0.40	0.9 0.9	0.9	0.45
1.0	0.9 0.9	0.9	0.50	1.0 1.0	1.00	0.6	1.3 1.2	1.25	0.80
5.0	4.0 4.0	4.0	3.60	4.6 4.6	4.6	4.2	4.8 4.8	4.8	4.35
20.0	18.4 18.4	18.4	18.0	19.2 19.2	19.2	18.8	(21.6) (21.6)	(21.6)	(21.15)
50.0	48.0 48.0	48.0	47.60	52.8 52.8	52.8	52.4	(48.0) (48.0)	(48.0)	(47.55)

In the case of Mason's method at the high concentration, where the color had to be determined on a small fraction of the solution obtained, the tone of the color was found to differ so much from that of the standards, that the results obtained are very inaccurate.

To determine the constancy of the results obtained by Mason's method two more series of determinations were made. Each series is independent of the other, and in each case both Mason's standards and the standard solution containing thirty parts per million of chloride were used for comparison. To obviate the above mentioned difficulty due to the difference in the tone of the color in the case of the solutions of high nitrate content, only one cubic centimeter portions of the solution containing twenty parts per million of nitrate, and half a cubic centimeter of that containing fifty parts per million, were used. As a result direct comparison, with the standards, without any dilution, was possible. The results follow:

TABLE X.—SHOWING SUPERIORITY OF MASON'S STANDARDS.

Amount of KNO ₃ added parts per million	Series A						Series B					
	Standard Solution			Mason's Standards			Standard Solution			Mason's Standards		
	Found	Avg.	Diff.	F'nd	Avg.	Diff.	Found	Avg.	Diff.	F'nd	Avg.	Diff.
none	0.30 0.20	0.25	....	0.50 0.40	0.45	....	0.30 0.30	0.30	....	0.40 0.40	0.40	....
0.5 0.5	0.50 0.60	0.55	0.30	0.85 0.95	0.90	0.45	0.60 0.50	0.55	0.25	1.0 0.9	0.95	0.55
1.0 1.0	0.70 0.80	0.75	0.50	1.30 1.40	1.35	0.90	0.70 0.70	0.70	0.40	1.30 1.30	1.30	0.90
5.0 5.0	3.80 3.60	3.70	3.45	5.00 5.20	5.10	4.65	3.80 3.80	3.80	3.50	5.20 5.20	5.20	4.80
20.0 20.0	18.40 19.20	18.80	18.55	2.00 2.00	2.00	19.55	20.00 19.00	19.50	19.20	2.00 2.00	20.00	19.45
50.0 50.0	48.00 48.00	48.00	47.75	2.5 2.5	2.50	49.55	48.00 48.00	48.00	47.70	2.5 2.5	2.50	49.45

In the following table the results are summed up. The known amounts of potassium nitrate added, and the amounts found are given for each series and by each method.

TABLE XI.—SUMMARY OF RESULTS SHOWING SUPERIORITY OF MASON'S STANDARDS.

Amount of KNO ₃ added parts per million	STANDARD SOLUTION				MASON'S METHOD			
	I	II	III	Avg.	I	II	III	Avg.
0.5	0.40	0.30	0.25	0.32	0.45	0.45	0.55	0.48
1.0	0.60	0.50	0.40	0.50	0.80	0.90	0.90	0.87
5.0	4.20	3.45	3.50	3.72	4.35	4.65	4.80	4.60
20.0	18.80	18.55	19.20	18.85	(21.15)	19.55	19.45	19.50
50.0	52.40	47.75	47.70	49.28	(47.55)	49.55	49.45	49.50

From these data it appears that the standards prepared according to Mason's method give the best results that have been obtained. The method involves a preliminary determination of the chloride content of the water, and of the approximate amount of nitrate present, in order that the standards may be prepared correctly and over the proper range. One difficulty met with is that when as much as thirty parts per million of chloride is added to the standard solutions before evaporation, good agreement between the standards themselves is not obtained. The standards made up one day may not match those made up the next. Moreover the intensity of the color may not increase exactly with the increase in nitrate content. Thus in one case the 1.3 cubic centimeter tube had a lighter color than the 1.2 cubic centimeter and the 2.5 cubic centimeter tube was darker than the 2.7 cubic centimeter. These variations seem unavoidable in the case of high chloride content. Nevertheless, in spite of this source of error, this method gives the best results; that is, the error due to variations in the standards is less than that due to using any other system of standards.

The second method which has been studied is the so-called "reduction method," which depends on the reduction of the nitrogen present in the water as either nitrate or nitrite to ammonia, and the quantitative determination of the ammonia formed. Suitable correction must then be made for the nitrogen present as nitrite and as free ammonia. The process as a whole thus involves two distinct operations, namely the reduc-

tion of the nitrogen to ammonia, and the quantitative determination of the ammonia.

Since the accuracy of the method of reduction must be measured by the determination of the ammonia produced, the methods for accomplishing the latter will be considered first. There are three possible methods. The determination of the ammonia in a measured quantity of water, after reduction; by means of Nessler's reagent *directly*; the distillation of a measured quantity of the water, after reduction, and the determination of the ammonia in the distillate by means of Nessler's reagent; and finally the distillation of a measured quantity of the water, after reduction, into an excess of a standard acid solution, and titration of the residual acid with a standard alkali solution.

The first method, the direct Nesslerization of measured quantities of the water, after reduction, is the simplest.* The chief objections to it are that the process of reduction produces a slight turbidity and sediment, and that the addition of the strongly alkaline Nessler reagent, especially in very hard waters, produces a heavy precipitate. As a result the delicacy of the determination is seriously interfered with. Another difficulty met in the case of a water of high nitrate content is that, since all the ammonia must be determined at once, only a small portion of the water, after reduction (one cubic centimeter or less) can be used for direct Nesslerization without exceeding the maximum limit for comparison with the standard tubes. If a distillation method is used, a larger sample may be taken, the ammonia obtained in four or five portions of the distillate, and a larger quantity determined with accuracy. Actual trial showed that in every case the addition of the Nessler reagent produced a heavy, colored precipitate, and gave a *lemon* yellow tinge to the solution, so that accurate comparison with the standards was impossible.†

The second method for determining the ammonia, namely the distillation of a measured quantity of the water, after reduction, and the determination of the ammonia in the distillate with the Nessler reagent, is open to very few objections on the ground of inaccuracy. However, it is cumbersome, and time consuming. As carried out, the details are as follows: A large distilling flask, of about two liters capacity, is filled with a water containing very little ammonia, and the contents made strongly alkaline with sodium hydroxide. The flask is connected with a condenser exactly as in the determination of free ammonia. The con-

* Hazen and Clark, J. Anal. Appl. Chem. 5: 3.

† A. H. Gill, J. Am. Chem. Soc. 16: 193 (1894).

tents of the flask are heated to boiling, and distillation continued until fifty cubic centimeters of the distillate give no reaction for ammonia with Nessler solution. The flask and contents are then allowed to cool for at least five minutes, and a measured quantity of the water under examination, after reduction, run into the flask from a pipette. The distillation is commenced at once, the distillate collected in Nessler tubes in fifty cubic centimeter portions, and the distillation continued until the last portion collected shows absence of ammonia when treated with the Nessler solution. The data given in the tables will show that good agreement between duplicate determinations was obtained. This method gave very satisfactory results, and was used in all the following determinations except where some other method is specified. By using several stills and running them at the same time that the free and albuminoid ammonia determinations were being made, the method required very little extra attention or time. Here again an objection rises in the case of waters of high nitrate content. The Nessler reagent method for the determination of ammonia is such a delicate one that the upper limit of its accuracy is soon reached. In other words the first portion of the distillate contains more ammonia than the highest of the comparison tubes. Thus in the case of a water containing twenty parts per million of nitrogen as nitrate, after reduction, ten cubic centimeters were put in the still, and the first fifty cubic centimeters of distillate contained ammonia corresponding to six cubic centimeters of the standard ammonium chloride solution. The darkest color which can be read at all accurately is that due to four cubic centimeters of the standard solution. In this case either less water may be put in the still, or the first portion of the distillate may be divided, but either alternative introduces a possibility of error.

To meet this objection the last method, namely the distillation into an excess of a standard acid solution and titration with standard alkali, was tried.

This method is not as delicate as the colorimetric method, and its usefulness would be confined to those cases where the nitrogen content is so high that only a very small quantity of the water could be used in applying the latter method. The results obtained are given below. The ammonia was distilled into an approximately N/50 sulphuric acid solution, and the excess of acid neutralized with a standard sodium hydroxide solution of about the same strength. Para nitro phenol was used as an indicator. Two independent sets of determinations were made. The results indicate that with very high nitrate content the ammonia had best be determined by distillation into standard acid.

TABLE XII.—DETERMINATION OF AMMONIA BY TWO METHODS.

Amt. of nitrogen in the water in parts per million	Found by distillation into standard acid		Found by Nessler method average of three determinations
	I	II	
20.00	18.18 18.30	19.75 19.25	18.87
50.00	44.93 43.31	43.70 42.91	43.71

A large number of methods for bringing about the reduction of the nitrate to ammonia have been suggested. Among them may be mentioned that of Foester,*—the reduction with metallic iron and potassium hydroxide in the presence of alcohol,—of Schmitt,†—the reduction with iron, zinc, and acetic acid,—of Ulsch,‡—the reduction with “ferrum reductum” and sulphuric acid,—and of Harrow,§—the reduction to nitrite in the presence of sulphanilic acid and *α*-naphthylamine. All these have given good results for relatively large amounts of nitrogen. The first three require the presence of the equivalent to half a gram of potassium nitrate, to obtain which it would be necessary to use one hundred cubic centimeters of a water containing seven hundred parts per million of nitrogen present as nitrate. The last method, Harrow's, is sensitive to only three tenths of a part per million.

Clearly none of these methods are applicable to the analysis of normal potable water without preliminary concentration,—the objections to which have already been mentioned. There are, however, two methods of bringing about the reduction which are sufficiently sensitive for the requirements of water analysis.

One by means of aluminium and caustic soda, and the other by means of the copper zinc couple in the presence of an excess of oxalic acid.||

* Given by Fricke, Analyst 16: 117.

† Given by Fricke, Analyst 16: 117.

‡ Zeit. anal. Chem. 30: 175; 31: 392.

§ J. Chem. Soc. 1891: 320.

|| Tiemann und Gaertner in “Die chem. und bacteriologische Untersuchung des Wassers,” Braunschweig, 1889: 208, 210, also give data obtained by the use of sodium amalgam as a reducing agent. The results were, however, very unsatisfactory.

The first of these, the reduction by means of aluminium and caustic soda, has given unsatisfactory results in the hands of other investigators.* The procedure adopted was to boil aluminium turnings in a small Erlenmeyer flask with weak sodium carbonate solution in order to drive out any free ammonia present. A measured amount of standard potassium nitrate solution was then added, also in some cases, in order to produce more nearly the conditions existing in the case of an actual water analysis, sodium chloride solution was introduced, and finally an excess of a sodium hydroxide solution which had been boiled till free from ammonia. The volume was then made up to twenty-five cubic centimeters with ammonia free water, and the flasks set aside over night. The next day the contents of each flask were rinsed with ammonia free water into a still, in which a weak sodium carbonate solution had been boiled until ammonia free, and the ammonia formed was distilled off and determined by Nesslerization of the distillate. Two blank determinations were made to test the purity of the reagents, and the average of the two values obtained was subtracted from each determination. The following table shows the unsatisfactory nature of the results obtained, all the figures referring to parts per million.

TABLE XIII.—RESULTS USING REDUCTION BY ALUMINIUM AND SODIUM HYDROXIDE.

Nitrogen added	No chlorides. Amount found	30 pts. per mill. Cl. Amount found	100 pts. per mill. Cl. Amount found	
blank	0.24	....	....	avg.
blank	....	....	0.20	2.20
0.20	0.14	0.10	0.06	
0.20	0.06	0.02	0.10	
1.00	0.10	0.50	0.22	
1.00	0.58	0.46	0.38	
5.00	1.26	0.90	1.10	
5.00	1.46	1.82	1.90	

Much more encouraging preliminary tests were obtained with the use of the copper-zinc couple as a reducing agent. Here the agreement obtained was good, in one case four duplicates on the same water gave

* cf. Hazen and Clark, A. H. Gill, Tiemans Gaertner, loc. cit.

respectively 0.36, 0.40, 0.45, and 0.45 parts per million of nitrogen present as nitrate. In a test on a water made up to contain 1.7 parts per million of nitrogen as nitrate, the average of two determinations was 1.35 parts per million; and on a water made up to contain 5.0 parts per million the average of two determinations in each of two distinct tests was 4.8 parts per million. This method was adopted as being the more promising of the two, and was applied to many waters in which the nitrates were also determined by the phenol sulphonic acid method. The data obtained are given in connection with the discussion of the relative value of the two methods. The method proved to be of the greatest value with waters in which the nitrate content was low and the chloride content high. Many waters showed absence of nitrates, proving that the manipulations involved in the method could be carried out without the introduction of ammonia as an impurity. As finally developed the details of the method were substantially those given by Cairns.* A wide-mouthed glass stoppered bottle of about one hundred and fifty cubic centimeters capacity was nearly filled with granulated zinc. The bottle was then filled with water and a few cubic centimeters of dilute hydrochloric acid (1:1) was added. The acid was allowed to act on the zinc for about five minutes so that a clean bright surface was obtained. Then the acid was poured out, the zinc thoroughly rinsed with distilled water, and then covered with a three per cent copper sulphate solution. The solution was left in contact with the zinc until an even and firmly adhering coating of copper was deposited. If the solution remains in contact with the zinc too long the coating of copper will not adhere properly. The copper sulphate solution was next poured off, and the zinc rinsed again with distilled water. Only freshly prepared zinc was used, and the same zinc was never used twice. When prepared, the bottle containing the zinc was thoroughly rinsed three times with the water to be analyzed, and then filled to within about a quarter of an inch of the stopper. About half a gram of crystallized, pure, ammonia free, oxalic acid was then added, the bottle thoroughly shaken, and set aside over night. The first sixty determinations were tested the next morning for the presence of nitrites, which would indicate incomplete reduction, but none were found. This test was then discontinued except in cases where the nitrate content was known to be very high, but even with a content of fifty parts per million nitrates were never found.

The effect of three factors was studied in detail, namely the presence of chlorides, the amount of oxalic acid used, and the time allowed for the

* Quantitative Analysis, 3d ed., p. 278.

reduction to take place.* To test the effect of the presence of chlorides duplicate determinations were made in a well water containing thirty-five parts per million of chlorine, and on a sample of the same water to which sodium chloride corresponding to one hundred parts per million had been added. In the first case 1.80 parts per million were found, and in the second 1.76 parts per million. The difference is within the limit of experimental error. To determine the effect of the amount of oxalic acid used three determinations were made. In one case 0.25 gram, in the second 0.50 gram, and in the third 1.00 gram of acid was used. The result in the first case was 1.32, in the second 1.28 and in the third 1.28 parts per million of nitrogen; the difference between the first and second of 0.04 parts per million is within the experimental error. It appeared, however, that on standing for some time the sample containing 0.25 gram of oxalic acid lost ammonia much faster than the others, so that the use of less than one half gram of oxalic acid per hundred and fifty cubic centimeters of water taken, does not seem to be wise. To test the effect of the time allowed for the reduction the following experiment was carried out. A large quantity, five hundred cubic centimeters, of a well water was treated with the copper-zinc couple and oxalic acid under exactly the conditions described above, and from time to time samples were withdrawn and the ammonia in them determined. The following table shows the results:

TABLE XIV.—RATE OF REDUCTION.

Time after addition of Oxalic acid		Nitrogen found in parts per million
Hours	Min.	
11	40	0.84
12	45	1.36
13	30	1.48
17	30	1.40
36	—	1.48
60	—	1.12

It appears, then, that the ammonia should be determined within fourteen to thirty-six hours after the oxalic acid has been added. The results obtained in determining the amount of acid to be used, indicate that with less acid the loss of ammonia is more rapid. Usually twenty-

* Tieman and Gaertner carried on the reduction at a temperature of 100° C. and obtained results much lower than those found when the reduction took place at lower temperatures.

TABLE XV.—COMPARISON OF SHEET AND GRANULATED ZINC FOR REDUCTION.

Amount of KNO added				I			II			III		
	Using Sheet Zn			Using Granulated Zn			Using Granulated Zn			Using Granulated Zn		
	F'nd	Avg.	Diff.	Found	Avg.	Diff.	Found	Avg.	Diff.	Found	Avg.	Diff.
none	0.08 0.08	0.08	....	0.12 0.12	0.12	....	0.12 0.12	0.12	....	0.16 0.16	0.16	....
0.50	0.48 0.36	0.42	0.34	0.60 0.72 0.72	0.68	0.56	0.44 0.44	0.44	0.32	0.76 0.84	0.80	0.64
1.00	0.80	0.80	0.72	1.12 1.12	1.12	1.00	0.96 0.92	0.94	0.72	1.16 1.16	1.16	1.00
5.00	3.20 3.20	3.20	3.12	4.20 4.30 4.20	4.23	4.11	3.3 3.2 3.3 3.4	3.33	3.21	4.20 4.30	4.25	4.09
20.00	.... ....	....	....	14.80 14.00	14.40	13.84	17.5	17.50	17.18	17.40	17.40	17.14
50.00	.... ....	....	....	37.00 43.00	40.00	39.44	36.10 36.50	36.25	35.93	40.00 38.0	39.00	38.84

TABLE XVI.—COMPARISON OF NESSLER AND TITRATION METHODS.

USING GRANULATED ZN					
Nessler Method		Titration Method		Titration Method	
Found	Avg.	Found	Avg.	Found	Avg.
4.60	4.60				
19.40	19.40	18.18 18.30	18.24	19.75 19.25	19.50
44.0	44.0	44.93 43.31	44.12	43.70 42.91	43.30

To compare the results which have been obtained by the phenol sulphonic acid and reduction methods, the data have been summarized in the following table. In the first column are given the average results obtained by the phenol sulphonic acid method using standards prepared according to Mason's modification. In the second column are the averages of the three best results obtained by the reduction method on the same solutions,—using the results obtained by the titration method for determining the ammonia at the two highest concentrations.

The solutions were prepared by adding known amounts of potassium nitrate to a well water, containing about thirty-five parts per million of chlorides and noting the difference in the amounts found. Only those differences are given. The figures all refer to parts per million.

TABLE XVII.—COMPARISON OF PHENOL SULPHONIC ACID AND REDUCTION METHODS.

Amount KNO ₃ added	Phenol Sulphonic Acid method. Mason's standards	Reduction method. Copper Zinc couple
0.50	0.43	0.51
1.00	0.87	0.91
5.00	4.60	4.27
20.00	19.45	18.87
50.00	49.50	43.71

It appears, then, that for low nitrate content the reduction method gives the best results, while if the nitrogen present exceeds five parts per million the phenol sulphonic acid method is the better.

The two methods were tested in actual practice by analyzing a

number of waters by both methods. The results are given in the following table. Neither method was perfected at the time the data was obtained, but nevertheless the results are fairly indicative of their relative value. All the figures refer to parts per million.

TABLE XVIII.—COMPARISON OF REDUCTION AND PHENOL SULPHONIC ACID METHODS.

Laboratory number	Reduction method	Phenol Sulphonic Acid method	Chloride content
3	0.40	0.35	37.00
	0.45	0.40	
10	0.23	none	36.23
13	0.06	none	16.60
14	none	none	12.82
15	4.0	6.00	22.00
	4.2		
16	0.11	none	18.44
17	none	none	56.50
18	0.24	none	41.10
19	0.08	none	26.30
20	0.10	none	52.80
21	0.18	none	37.50
22	0.08	none	48.70
23	0.04	none	33.40
25	0.72	0.50	39.20
		0.53	
24	1.0	0.9	37.30
	1.3	0.9	
26	none	none	13.82
27	none	none	17.50
28	none	none	17.70
29	0.16	0.10	24.10
		0.15	
30	none	none	36.90
31	1.23	1.5	14.30
		2.0	
32	none	none	19.80
33	0.15	none	20.50
34	0.15	none	14.50
35	0.08	none	10.60
36	0.02	none	9.40
37	none	none	40.57
39	2.00	1.8	25.45
		1.6	
40	none	none	31.81
41	none	none	14.75
42	none	none	61.50
43	0.18	none	135.50
44	0.11	none	29.50

TABLE XVIII (CONTINUED).

Laboratory number	Reduction method	Phenol Sulphonic Acid method	Chloride content
45	0.26	none	42.41
46	0.72	0.3	42.41
47	2.04	2.0	30.40
		2.3	
48	none	none	79.20
49	0.12	none	27.70
50	0.04	none	27.85
51	0.10	none	37.15
52	0.16	0.25	38.26
		0.30	
53	0.14	0.20	45.92
		0.20	
54	none	none	37.43
55	0.11	none	37.53
68	0.19	0.25	24.25
80	0.46	0.35	173.89
82	0.30	0.25	20.80
		0.27	
84	0.84	0.78	14.75
97	2.44	2.30	30.89
98	1.60	1.70	26.55
99	0.44	0.47	27.84
100	0.36	0.40	26.18

The data given may be summarized as follows: Fifty-one waters were examined by both methods. Of these twelve gave no nitrate by either method. Twenty gave amounts of nitrate varying from 0.02 to 0.26 parts per million by the reduction method, and none at all by the phenol sulphonic acid method. The other nineteen gave nitrate by both methods. In no case was nitrate found by the phenol sulphonic method and not by the reduction method.

Of the twenty cases where nitrates were found by the reduction method and not by the phenol sulphonic acid method, fifteen gave amounts between 0.02 and 0.15 parts per million and five between 0.18 and 0.26 parts per million. In the group of fifteen the chlorides present ranged from 9.40 to 52.80 parts per million. In the group of five the chloride content varied from 36.23 to 135.50 parts per million. In no case was as much as 0.18 parts per million of nitrogen lost by the phenol sulphonic acid method in the presence of less than 36.23 parts per million of chlorides.

Of the nineteen cases where nitrates were found by both methods, in ten the reduction method gave the highest value, and in nine the

phenol sulphonic acid method. This result cannot be explained by variation in the chloride content, nor can it be said from these data that one method is better than the other for low or for high nitrate content. In the ten cases where the reduction method gave the highest result the average difference was 0.16 parts per million. In the nine cases where the highest result was obtained by the phenol sulphonic acid method, discarding No. 15, one of the first analyses and an extreme case due possibly to faulty analysis, the average difference was 0.13 parts per million.

From the data presented the following conclusions may be drawn. For waters containing large amounts of chlorides the nitrogen present as nitrate may best be determined by the "reduction method." If the result of the determination indicates a nitrogen content in excess of five parts per million, the determination should be repeated, using the phenol sulphonic acid method and standards prepared according to Mason's method. Neither method gives strictly quantitative results. The experience obtained in this investigation indicates that an error of ten per cent may be made in the case of low nitrates using the reduction method, while with very high nitrate content, twenty parts per million or over, the phenol sulphonic acid method gives results within three per cent of the theoretical.

One limitation to the application of the reduction method should be considered, and that is met in the case of sewage or water containing very large amounts of vegetable matter. In such cases Parvis and Courtland* have found that the reduction method gives larger quantities of ammonia than correspond to the nitrates and nitrites in the water. They conclude that the copper-zinc couple reduces more of the nitrogen present as organic matter to ammonia. Tiemann and Gaertner, in the case of solutions to which egg albumin and caramel have been added, conclude that the albumin gives too high a result, while the caramel retards the reduction. None of these results, however, interfere with the application of the method to normal, potable waters, and it may still be regarded as the best method available for normal waters of high chloride content.

THE DETERMINATION OF THE CHLORIDES.

The chlorides were determined in one hundred cubic centimeter portions by the usual method of titration with silver nitrate solution in the presence of potassium chromate as an indicator. In a few extreme cases smaller amounts of the samples were used.

* Proc. Camb. Phil. Soc. 14: 441 (July 16).

THE DETERMINATION OF THE HARDNESS AND TOTAL SOLIDS.

Hehner's acid method was used in the determination of both the temporary and the permanent hardness. As determined by this method the temporary hardness is the same as the "alkalinity." Erythrosine in the presence of chloroform was used as an indicator. The results were expressed in terms of parts per million of calcium carbonate.

The total solids were determined by the evaporation of one hundred cubic centimeter samples in weighed platinum dishes. The dishes containing the residues were heated for an hour in an air bath at 105° C. After the first weighing the heating was repeated for half an hour, or until a constant weight was obtained. The change of the residue on ignition was determined by holding the platinum dishes in the flame of a burner. The blackening which resulted was described as "very slight," "slight," "distinct," "decided," "considerable," and "excessive." The loss in weight on ignition was not determined.

The analytical results obtained are presented in the Table XIX. Certain determinations, namely those concerning the turbidity, sediment, color, odor and change on ignition are omitted for the sake of conciseness. The results of these determinations are discussed on page 39.

The area under investigation has been subdivided into sections, with reference to the various watersheds, each subdivision consisting of the watersheds either of one stream with its tributaries, or of a group of small independent streams. The subdivisions are designated as "E" or "W" according to their location on the eastern or western slope of the main ridge, and are numbered from north to south. There are thirteen such subdivisions on each side. The exact boundaries of these subdivisions are indicated by broken lines on the accompanying map. This map shows also the streams and their main tributaries, the principal towns, and the location of each point of collection of a sample. These points are indicated by a circle, followed by a number which is the laboratory number of one sample collected at the indicated place. With the aid of this key number, the analyses of the other samples from the same place may be found in the table.

The table is arranged as follows: In the first column is given the number of the subdivision, thus "W.6" means the sixth division from the north on the western slope, and reference to the map will show that this is the area drained by "Frenchman's creek." The subdivisions are arranged in order according to their location from north to south on the eastern, and then on the western slopes. In the second column, headed

"class," is given first a letter indicating the classification of the water according to the system described on page 11, and then a symbol indicating whether the source be a stream, spring or catchment reservoir. "St." indicates a stream, "Sp." indicates a spring, and "R" indicates a catchment reservoir whether artificial or a natural pond. The third column gives the date of the analysis in month and year. The arrangement of the analyses in the table is uniformly in the order: fall—winter—spring. The fourth column contains the laboratory number of the analysis, and the other columns give the results of the analysis expressed in parts per million.

DISCUSSION OF ANALYTICAL DATA.

The results of the determinations of turbidity, sediment, color, odor, and change on ignition were omitted from the table. They may be summarized as follows:

Most of the samples showed very slight or no turbidity. As a class the catchment reservoirs showed greater turbidity than did the streams. A few samples from streams collected after heavy rainfall showed marked turbidity. The samples bearing the following laboratory numbers showed turbidity graded "distinct" or "decided,"*—17, 49, 67, 75, 76, 82, 99, 111, 112, 114, 115, 116, and 185.

The sediment was generally very slight. Like the turbidity it was more marked in samples from catchment reservoirs than from streams, and was pronounced in those from streams after heavy rainfall. It was graded above "slight"* in the samples numbered 18, 19, 46, 75, 76, 82, 99, 115, and 185. Neither the sediment or the turbidity was found to have an appreciable effect on the more important constituents.

The only samples where any appreciable color* was detected were the following: "very slight yellowish" in 27; "slight yellowish" in 11, 17, 18, 19, 20, and 30; "decided yellowish" in 10; "slight brownish" in 46, 49, 51, 82, 96, 98, 99, 103 and 161; "brownish" in 100, 111, 112, 115, 116, and 185.

The odor was determined in every sample before and after heating. In 72 samples, of which 15 samples were from deep wells, no odor could be detected. The most common odor was "vegetable" and next to it "earthy." The "vegetable" odor was most marked during the winter months, and the "earthy" during the fall months. In all 62 samples gave a "vegetable" odor, of which 23 gave less odor when heated, 27 gave more, and 12 showed no difference. An "earthy" odor was detected in

* cf. page 12.

TABLE XIX.—ANALYTICAL DATA FROM SURFACE WATERS.

Watershed	Class	Date	Laboratory Number	Ammonia Free	Ammonia Albuminoid	Nitrites	Nitrates	Chlorides	Hardness Total	Hardness Temporary	Hardness Permanent	Free Alk. Carbonates	Total Solids
E. 1.	B R	8/08	85.1	.....	.....	.....	.....	44.74	.....	.....	.....	.....	.....
		3/08	111	0.098	0.220	0.001	0.24	31.72	149.6	65.6	84.0	.....	170
		6/08	70.1	.....	.....	.....	.....	37.64	.....	.....	.....	.....	.....
E. 2.	C R	3/08	45.1	.....	.....	.....	.....	23.97	.....	.....	.....	.....	.....
	D R	3/08	112	0.096	0.534	0.001	0.20	86.67	103.5	79.02	.....	24.48	325
	A R	9/08	189	none	0.102	none	none	23.33	81.26	81.26	none	.....	140
		2/08	106	0.002	0.122	none	none	19.36	70.64	65.20	5.44	.....	130
		6/08	141	0.004	0.094	none	none	21.70	83.42	71.20	12.22	.....	130
E. 3.	B St	2/08	39.1	.....	.....	.....	.....	25.35	.....	.....	.....	.....	.....
	A St	9/08	92.1	.....	.....	.....	.....	25.15	.....	.....	.....	.....	.....
		2/08	41.1	.....	.....	.....	.....	19.36	.....	.....	.....	.....	.....
	A St	6/08	62.1	.....	.....	.....	.....	19.98	.....	.....	.....	.....	.....
		9/08	89.1	.....	.....	.....	.....	23.04	.....	.....	.....	.....	.....
	B R	8/07	19	0.008	0.242	none	none	26.3	119.8	96.4	.....	23.4	242
		2/08	102	0.010	0.130	0.0025	0.76	22.59	111.5	107.07	4.43	.....	188
	D St	6/08	138	0.024	0.140	0.0005	0.44	25.36	120.7	120.7	none	.....	188
		9/08	186	0.100	0.248	none	none	26.30	130.73	122.4	8.33	.....	194
	B R	8/07	18	0.012	0.118	none	none	41.1	286.7	250.2	.....	36.5	412
E. 4.	B Sp	8/07	17	0.010	0.206	none	none	56.5	120.9	109.2	.....	11.7	290
		3/07	31	0.022	0.052	0.003	1.7	14.3	177.7	164.0	13.7	.....	250
	A St	2/08	84	none	0.070	0.002	0.84	14.75	148.65	131.0	17.65	.....	222
		5/08	131	0.012	0.030	0.0005	none	13.52	160.9	147.2	.....	13.7	235
	D St	10/07	9.1	.....	.....	.....	.....	20.00	.....	.....	.....	.....	.....
E. 5.	A St	2/08	37.1	.....	.....	.....	.....	15.86	.....	.....	.....	.....	.....
		6/08	77.1	.....	.....	.....	.....	18.42	.....	.....	.....	.....	.....
	D St	10/07	8.1	.....	.....	.....	.....	30.15	.....	.....	.....	.....	.....
		2/08	36.1	.....	.....	.....	.....	22.22	.....	.....	.....	.....	.....
	D St	6/08	76.1	.....	.....	.....	.....	33.60	.....	.....	.....	.....	.....
		2/08	32.1	.....	.....	.....	.....	24.43	.....	.....	.....	.....	.....
	D St	9/07	2.2	.....	.....	.....	.....	63.6	.....	.....	.....	.....	.....
	A St	2/08	30.1	.....	.....	.....	.....	18.9	.....	.....	.....	.....	.....
		2/08	31.1	.....	.....	.....	.....	15.67	.....	.....	.....	.....	.....
	A St	8/08	172	none	0.028	none	none	24.38	243.5	204.2	.....	39.3	345
		2/08	83	0.006	0.048	none	none	12.91	128.5	115.0	13.5	.....	215

E. 5.	B R	5/08	132	none	0.008	none	19.68	213.6	200.7	.....	12.9	335
		9/07	32	0.008	0.070	none	19.8	106.2	97.9	.....	8.3	230
	B R	2/08	85	0.030	0.116	0.007	19.82	146.68	141.8	4.88	.....	275
		5/08	130	0.020	0.060	none	20.3	129.7	127.5	.....	2.21	240
	B R	8/08	173	none	0.160	none	24.0	116.9	97.5	.....	19.4	220
		9/07	30	0.008	0.074	none	36.9	204.7	190.0	14.7	.....	377
	B St	2/08	82	0.020	0.140	0.006	20.8	109.6	78.2	31.4	.....	257
		5/08	133	0.018	0.092	none	34.56	192.0	154.6	37.4	.....	360
	B St	8/07	10	0.008	0.054	none	26.23	469	212	257	.....	843
		1/08	68	0.050	0.054	0.003	24.25	293	117	176	.....	640
E. 5.	C St	3/08	114	0.044	0.092	0.005	15.67	203	109	93.5	.....	552
		5/08	137	0.004	0.056	none	26.60	255.9	163.3	92.6	.....	750
	C St	6/08	170	none	0.100	none	32.16	293.7	205.6	88.1	.....	785
		8/07	11	0.006	0.060	0.001	44.8	246	242.4	.....	3.6	429
	B St	3/08	115	0.020	0.038	0.004	22.4	210	147.2	62.8	.....	420
		6/08	171	none	0.062	none	47.23	260.04	254.1	5.94	.....	450
	A St	3/08	117	0.012	0.018	none	15.58	100.88	4.08	96.8	.....	394
	C St	3/08	48.1	.....	.....	.....	14.75	.....	.....	.....	.....	.....
	B R	9/07	2.1	.....	.....	.....	41.5	.....	.....	.....	.....	.....
		1/08	67	0.032	0.236	none	9.77	46.4	37.5	8.9	.....	84
E. 6.	C R	5/08	136	0.004	0.112	none	9.03	37.9	37.9	none	.....	70
		5/08	58.1	.....	.....	.....	13.52	.....	.....	.....	.....	.....
	B Sp	5/08	59.1	.....	.....	.....	14.40	.....	.....	.....	.....	.....
		9/08	88.1	.....	.....	.....	13.92	.....	.....	.....	.....	.....
	B St	9/08	87.1	.....	.....	.....	21.60	.....	.....	.....	.....	.....
		1/08	69	0.012	0.036	none	18.62	222.1	205.0	17.1	.....	284
	C St	5/08	135	0.010	0.028	none	16.13	243.6	239.4	.....	4.25	315
		8/07	12	0.005	0.037	0.002	35.04	230	217	.....	13	351
	C Sp	1/08	66	0.010	0.038	none	25.35	223.7	204.0	19.7	.....	302
		5/08	134	0.010	0.022	none	23.32	231.8	231.8	none	.....	320
E. 6.	C Sp	8/07	15	0.008	0.064	0.110	22.0	160.1	126.8	33.3	.....	278
		3/08	116	0.018	0.060	0.008	14.38	138.1	103.8	34.3	.....	252
	C Sp	6/08	78.1	.....	.....	.....	25.92	.....	.....	.....	.....	.....
		11/07	13.1	.....	.....	.....	22.68	.....	.....	.....	.....	.....
	B Sp	11/07	14.1	.....	.....	.....	14.38	.....	.....	.....	.....	.....
		11/07	16.1	.....	.....	.....	28.21	.....	.....	.....	.....	.....
	C Sp	11/07	21.1	.....	.....	.....	23.00	.....	.....	.....	.....	.....
		11/07	21.1	.....	.....	.....	23.00	.....	.....	.....	.....	.....
	C Sp	11/07	21.1	.....	.....	.....	23.00	.....	.....	.....	.....	.....
		11/07	21.1	.....	.....	.....	23.00	.....	.....	.....	.....	.....

Watershed	Class	Date	Laboratory Number	Ammonia Free	Ammonia Albuminoid	Nitrites	Nitrates	Chlorides	Hardness Total	Hardness Temporary	Hardness Permanent	Free Alk. Carbonates	Total Solids
E. 7.	A St	8/07	16	0.009	0.033	none	none	18.44	247.2	227.2	.....	20.0	313
		3/08	113	0.008	0.006	none	0.44	15.20	219.2	192.0	.....	27.2	267
	A St	6/08	169	none	0.030	none	none	18.05	254.1	254.1	none	.....	295
		3/08	46.1	.....	.....	.....	.....	15.86	.....	.....	.....	.....	.....
	A St	6/08	79.1	.....	.....	.....	.....	36.19	.....	.....	.....	.....	.....
E. 8.	A St	3/08	47.1	.....	.....	.....	.....	10.42	.....	.....	.....	.....	.....
		6/08	80.1	.....	.....	.....	.....	20.45	.....	.....	.....	.....	.....
	A St	8/07	13	0.006	0.037	none	none	16.60	238.2	234.5	.....	3.7	293
		1/08	78	0.004	0.010	0.001	none	16.04	227.3	218.8	8.5	.....	287
	A St	5/08	128	none	0.018	none	0.28	16.41	205.7	202.5	.....	3.2	275
E. 9.		1/08	79	none	0.008	0.0005	none	15.67	241.0	226.0	15.0	.....	293
		5/08	55.1	.....	.....	.....	.....	16.90	.....	.....	.....	.....	.....
	A St	8/07	14	0.003	0.032	none	none	12.82	158.1	145.0	13.1	.....	214
		1/08	81	none	0.004	0.001	none	12.08	217.5	194.0	23.5	.....	267
	C St	5/08	129	none	0.028	none	0.56	13.14	163.5	154.0	9.5	.....	200
	C St	1/08	29.1	.....	.....	.....	.....	16.78	.....	.....	.....	.....	.....
	C St	1/08	29.2	.....	.....	.....	.....	16.87	.....	.....	.....	.....	.....
		1/08	29.3	.....	.....	.....	.....	18.35	.....	.....	.....	.....	.....
		5/08	56.1	.....	.....	.....	.....	20.74	.....	.....	.....	.....	.....
	D St	9/07	25.	0.030	0.094	0.006	0.72	39.2	283.5	265.0	18.5	.....	461
		5/08	57.1	.....	.....	.....	.....	31.98	.....	.....	.....	.....	.....
	B St	9/07	26	0.004	0.018	none	none	13.82	233.5	225.4	.....	8.1	297
		4/08	119	0.014	0.006	none	0.16	14.49	211.65	202.3	9.35	.....	285
	A St	9/07	27	0.010	0.040	none	none	17.5	210.5	208.2	.....	2.3	295
		1/08	71	0.012	0.014	none	none	17.52	185.6	164.5	21.1	.....	285
	A St	4/08	120	0.018	0.030	none	0.80	17.09	185.3	185.3	none	.....	283
E. 9.	A St	9/07	1.1	.....	.....	.....	.....	15.68	.....	.....	.....	.....	.....
	A St	9/07	1.2	.....	.....	.....	.....	15.68	.....	.....	.....	.....	.....
	A St	9/07	1.3	.....	.....	.....	.....	15.70	.....	.....	.....	.....	.....
	A St	9/07	1.4	.....	.....	.....	.....	15.20	.....	.....	.....	.....	.....
	A St	9/07	1.5	.....	.....	.....	.....	14.76	.....	.....	.....	.....	.....
	A St	9/07	1.6	.....	.....	.....	.....	14.76	.....	.....	.....	.....	.....
	A St	9/07	1.7	.....	.....	.....	.....	15.68	.....	.....	.....	.....	.....
	A St	9/07	1.8	.....	.....	.....	.....	16.1	.....	.....	.....	.....	.....

Watershed	Class	Date	Laboratory Number	Ammonia Free	Ammonia Albuminoid	Nitrites	Nitrates	Chlorides	Hardness Total	Hardness Temporary	Hardness Permanent	Free Alk. Carbonates	Total Solids
E. 11.	D St	9/07	33	0.012	0.044	none	0.15	20.5	161.6	156.8	4.8	.....	255
		6/08	64.1	.....	.....	.....	.....	18.11	.....	.....	.....	.....	.....
	B St	8/08	176	none	0.018	none	none	13.92	203.66	192.1	11.56	.....	273
E. 12.	C St	8/08	177	none	0.076	none	0.080	15.93	181.34	174.2	7.14	.....	260
		2/08	86	0.016	0.024	0.001	none	10.14	128.46	104.0	24.46	.....	217
	B St	6/08	145	0.006	0.028	none	0.24	11.52	168.3	128.5	.....	39.8	265
	B St	8/08	81.1	.....	.....	.....	.....	12.19	.....	.....	.....	.....	.....
	B St	8/08	82.1	.....	.....	.....	.....	16.61	.....	.....	.....	.....	.....
		2/08	87	0.020	0.010	none	none	10.88	123.58	109.0	14.58	.....	163
E. 13.	B St	6/08	146	0.006	0.014	none	0.80	13.44	210.8	202.3	.....	8.5	280
		2/08	33.1	.....	.....	.....	.....	10.42	.....	.....	.....	.....	.....
		6/08	65.1	.....	.....	.....	.....	14.60	.....	.....	.....	.....	.....
	A St	8/08	178	none	0.028	none	0.12	12.48	212.66	209.6	3.06	.....	275
		2/08	88	none	0.020	none	none	8.67	118.75	108	10.75	.....	155
		6/08	147	0.006	0.016	none	0.24	9.60	176.5	173.3	.....	3.2	223
C St		8/08	83.1	.....	.....	.....	.....	14.11	.....	.....	.....	.....	.....
		2/08	34.1	.....	.....	.....	.....	10.05	.....	.....	.....	.....	.....
		6/08	66.1	.....	.....	.....	.....	11.81	.....	.....	.....	.....	.....
D St		8/08	179	none	0.052	none	none	34.94	353.04	313.6	39.44	.....	568
		2/08	89	0.012	0.020	0.001	none	10.42	138.05	124.0	14.05	.....	190
		6/08	148	none	0.026	none	0.48	22.55	272.8	253.8	.....	19.0	380
W. 1.	B St	6/08	154	none	0.258	none	0.52	53.0	141.4	137.8	.....	3.6	240
	B St	6/08	71.1	.....	.....	.....	.....	41.8	.....	.....	.....	.....	.....
	B Sp	8/08	182	none	0.022	none	0.44	62.02	116.1	81.1	35.0	.....	240
W. 2.		6/08	155	none	0.022	none	0.28	56.3	103.57	85.17	18.40	.....	235
	B Sp	8/08	185	none	0.014	none	2.16	56.83	184.6	156.7	27.9	.....	365
	A St	8/08	183	none	0.052	none	0.08	28.80	86.55	86.55	none	.....	248
A St		6/08	156	none	0.022	none	0.28	28.14	180.1	177.04	.....	3.06	235
		8/08	184	none	0.012	none	0.44	22.37	69.02	69.02	none	.....	125
		6/08	157	none	0.014	none	0.56	21.80	69.8	65.04	.....	4.76	128
W. 3.	B St	8/08	86.1	.....	.....	.....	.....	23.23	.....	.....	.....	.....	.....
		6/08	72.1	.....	.....	.....	.....	23.04	.....	.....	.....	.....	.....
	A St	10/07	46	0.078	0.266	0.005	0.8	42.41	66.9	58.3	8.6	.....	227
		2/08	96	none	0.070	none	0.2	40.11	55.5	36.8	18.7	.....	165

W.4.	A St	6/08	158	none	0.080	none	0.56	43.80	71.3	65.35	....	5.95	175
		9/07	39	0.006	0.076	0.001	2.0	25.45	59.8	43.2	16.6	....	132
		2/08	98	0.008	0.050	none	1.6	26.55	56.4	37.7	18.7	....	115
	B Sp	6/08	159	none	0.018	0.0005	2.0	35.06	57.2	57.2	none	....	130
		10/07	47	0.002	0.074	none	2.1	30.4	64.8	48.7	16.1	....	162
		2/08	97	none	0.044	none	2.4	30.89	67.5	43.4	24.1	....	157
	D St	6/08	160	none	none	none	2.7	30.4	63.6	60.54	....	3.06	132
	C St	9/07	6.1	....	....	....	....	47.48	....	....	....	....	....
		9/07	7.1	....	....	....	....	40.11	....	....	....	....	....
		2/08	38.1	....	....	....	....	34.11	....	....	....	....	....
W.5. W.6.	B St	6/08	74.1	....	....	....	....	48.67	....	....	....	....	....
		9/07	40	none	0.112	none	none	31.81	91.9	69.6	22.3	....	160
		2/08	99	none	0.080	0.0005	0.45	27.84	63.8	45.4	18.4	....	155
		6/08	75.1	....	....	....	....	39.64	....	....	....	....	....
W.7.	B St	10/07	48	none	0.118	none	none	79.2	152.7	128.4	24.3	....	362
	B St	10/07	49	0.010	0.090	0.004	0.12	27.7	99.1	88.4	10.7	....	232
		2/08	100	0.008	0.104	0.0005	0.16	26.18	75.4	56.4	19.0	....	155
		6/08	161	0.004	0.052	0.002	none	27.84	92.5	87.4	....	5.1	155
	A R	9/08	187	0.004	0.090	none	none	21.22	59.33	59.33	none	....	105
		2/08	103	0.008	0.152	0.001	0.24	17.06	48.78	40.8	7.98	....	115
		6/08	139	0.016	0.022	none	0.48	19.30	55.21	49.6	5.61	....	110
	A St	9/08	90.1	....	....	....	....	24.58	....	....	....	....	....
		2/08	104	none	0.054	0.0005	0.68	21.11	64.22	56.75	7.47	....	133
		6/08	60.1	....	....	....	....	24.00	....	....	....	....	....
W.8.	A R	9/08	188	0.006	0.082	0.001	none	27.98	112.03	109.31	2.72	....	185
		2/08	105	0.020	0.064	0.002	0.20	18.44	133.94	125.10	8.84	....	185
		6/08	140	0.018	0.034	none	0.64	26.20	119.65	108.6	11.05	....	180
	A St	9/08	91.1	....	....	....	....	35.23	....	....	....	....	....
W.9.		2/08	40.1	....	....	....	....	21.76	....	....	....	....	....
		6/08	61.1	....	....	....	....	31.68	....	....	....	....	....
	A St	9/07	37	0.002	0.024	none	none	40.57	213.1	202.9	10.2	....	311
		2/08	101	0.012	0.076	0.0005	0.38	33.19	148.42	135.0	13.42	....	265
		6/08	167	none	0.060	none	0.12	38.60	212.5	209.4	3.10	....	322
	C St	9/07	5.1	....	....	....	....	39.65	....	....	....	....	....
	A St	10/07	50	0.002	0.080	none	0.04	27.85	102.7	92.5	10.2	....	205
	C St	10/07	11.1	....	....	....	....	36.51	....	....	....	....	....
		10/07	51	0.018	0.098	0.002	0.12	37.15	117.6	78.7	38.9	....	273
	D R	10/07	51	0.018	0.098	0.002	0.12	37.15	117.6	78.7	38.9	....	273

Watershed	Class	Date	Laboratory Number	Ammonia Free	Ammonia Albuminoid	Nitrites	Nitrates	Chlorides	Hardness Total	Hardness Temporary	Hardness Permanent	Free Alk. Carbonates	Total Solids
W.7. W.8.	D St	10/07	45	0.016	0.108	0.001	0.28	42.41	307.4	274.7	32.7	.....	558
	A Sp	10/07	41	0.018	0.030	none	none	14.75	43.9	15.6	28.3	.....	128
W.9		2/08	94	none	0.024	none	none	12.91	47.3	16.9	30.4	.....	112
	B St	6/08	162	0.008	0.020	none	0.44	14.40	42.14	26.84	15.30	.....	120
		10/07	44	0.016	0.118	0.001	0.12	29.5	258.7	252.8	5.9	.....	440
	A St	6/08	165	none	0.048	0.0005	0.20	27.56	284.0	277.88	.....	6.12	403
W.10.	C St	6/08	166	none	0.022	none	0.16	21.52	264.4	216.6	47.8	.....	372
		10/07	10.1	.....	.....	.....	.....	33.19	.....	.....	.....	.....	.....
	C St	10/07	43	0.014	0.160	0.002	0.20	135.5	323.4	255.9	67.5	.....	823
		6/08	164	0.030	0.102	0.003	0.16	120.0	337.6	272.0	65.6	.....	708
W.11.	B St	10/07	42	0.016	0.046	0.0005	none	61.5	224.8	219.4	.....	5.4	429
		2/08	95	0.004	0.052	0.0005	none	31.35	145.1	124.5	20.6	.....	250
		6/08	163	none	0.050	none	0.20	47.25	231.2	212.5	.....	18.7	363
	C Sp	8/08	84.1	.....	.....	.....	.....	12.48	.....	.....	.....	.....	.....
W.12.	A St	8/07	23	0.038	0.130	none	none	33.4	340.5	262.5	78.0	.....	620
		2/08	90	0.044	0.160	0.0005	0.40	20.28	230.6	155.2	75.4	.....	400
		5/08	127	0.008	0.024	0.0005	0.40	34.84	321.9	252.2	69.7	.....	600
	C St	8/07	22	0.042	0.056	none	0.08	48.7	290.2	241.0	49.2	.....	532
W.13.		2/08	35.1	.....	.....	.....	.....	23.97	.....	.....	.....	.....	.....
		5/08	54.1	.....	.....	.....	.....	40.2	.....	.....	.....	.....	.....
	C St	8/07	21	0.024	0.074	0.004	0.18	37.5	320.0	268.1	51.9	.....	616
		2/08	91	0.034	0.158	0.001	0.20	22.59	197.8	142.	55.8	.....	383
W.14.		5/08	123	0.008	0.046	0.004	0.52	30.36	322.6	266.0	56.6	.....	585
	C St	2/08	93	0.014	0.134	none	0.28	27.20	127.62	108.5	19.12	.....	275
		5/08	126	0.014	0.050	0.002	0.44	72.00	207.4	207.4	none	.....	445
	A St	8/08	180	0.010	0.052	none	none	50.20	237.09	224.0	13.09	.....	406
W.15.		6/08	149	none	0.054	none	0.16	37.22	215.5	212.4	3.1	.....	365
	B St	8/08	181	0.016	0.074	0.001	0.44	55.82	334.9	334.9	none	.....	545
		6/08	150	0.012	0.068	0.005	0.32	46.50	309.6	296.0	13.6	.....	490
	B St	8/07	20	0.016	0.058	none	0.10	52.8	243.4	243.4	none	.....	452
W.16.		2/08	92	0.008	0.050	none	none	21.67	100.36	94.2	6.16	.....	248
		5/08	51.1	.....	.....	.....	.....	41.50	.....	.....	.....	.....	.....
	B St	5/08	124	0.014	0.042	none	0.72	42.5	213.25	205.6	7.65	.....	385
	D St	5/08	53.1	.....	.....	.....	.....	49.9	.....	.....	.....	.....	.....

31 samples, of which 20 gave less odor when heated, 8 more, and 3 showed no difference. The "earthy" odor, therefore, is generally decreased by heating. Samples numbered 19 and 106, both from catchment reservoirs, gave a distinct "fishy" odor when heated, and sample 133, also from a reservoir, gave a decided "fishy" odor when cold which was decreased by heating. The following exceptional odors were also noted: 22 gave cold, faint "musty," hot, none; 179 cold, faint "mouldy," hot, faint "mouldy"; 39 and 40 cold, faint "mouldy," hot, very faint "mouldy"; 51 cold, faint "mouldy," hot, distinct "mouldy." A study of the data leads to the conclusion that the streams generally have a faint "vegetable" odor which is especially marked during the winter months, an "earthy" odor in the fall is not uncommon, and absence of odor is most common in the spring. The water from the deep wells may have a faint "earthy" odor, but is generally odorless.

The blackening of the residue on ignition in the samples from streams was generally "very slight" or "slight."* Thus 4 samples showed "no" blackening, 29 "very slight," 33 "slight," 19 "distinct," 19 "decided," and 5 "considerable." The amount of blackening was somewhat greater during the winter and spring than during the summer and fall. This is to be expected, since the rains wash considerable quantities of animal and vegetable matter into the streams. The streams on the western slope gave somewhat greater amounts of blackening than those on the eastern, but the difference was not very marked. The Corte Madera Creek gave uniformly high results, which, together with the abnormally high total solids shown by the same samples, may be due to the fact that the bed of the stream was greatly disturbed by the earthquake of 1906. Extensive landslides along its banks completely choked the stream with vegetable and mineral debris; and in many places forced it to seek a new course. When the samples were taken sufficient time for the restoration of the normal condition of the stream bed had not elapsed.

The samples from springs showed either "slight" or "very slight" blackening. Those from catchment reservoirs showed generally "distinct" or "decided," and were highest during the fall months at the end of the dry season. Certain reservoirs gave uniformly somewhat higher results than others. The samples for the deep wells showed either "very slight" or "no" blackening.

In the further discussion of the analytical data the several substances determined will be taken up in the order in which they are given in the table. The streams, springs, and catchment reservoirs will be considered first, and the wells will be dealt with in a separate class.

* cf. page 38.

FREE AND ALBUMINOID AMMONIA.

The amount of organic matter in the water of a stream is independent of the geographical location of the watershed, and of the wind and fog conditions, but is markedly influenced by the surrounding vegetation and the time of the year. On the eastern slope the free ammonia during the fall months varied from "none" to 0.010 parts per million. It was about the same in the northern part of the western slope, but higher in subdivisions W. 8 to W. 13. Here the highest content was 0.038 parts per million, and the average 0.022 parts per million. These divisions include the watersheds drained by the Purisima, Lobitos, Tunitas, San Gregorio and Pescadero creeks, and are the most heavily wooded of any in the area investigated. The ammonia content of these streams is at all seasons different from that of the streams whose watersheds are less heavily wooded. During the winter months the streams on the eastern side generally show a slight increase in free ammonia, reaching a maximum of 0.020 parts per million. The same is true on the west, except in divisions W. 11 and W. 13, where the increase is up to 0.044 parts per million. In the spring there is a general decrease in the free ammonia throughout the whole territory to less than the fall content. On the east the range is about the same, but the average lower; on the west, especially in divisions W. 8 to W. 13, the decrease is more marked, the maximum being 0.014 parts per million.

The following maximum values may be taken for class "A" and "B" streams. In the fall, generally 0.010 parts per million, in especially heavily wooded regions 0.040 parts per million. In the winter generally 0.020 parts per million, in especially heavily wooded regions 0.050 parts per million. In the spring generally lower than in the fall in individual cases with a maximum of 0.010 parts per million except in heavily wooded regions where the maximum may be 0.015 parts per million.

The amount of albuminoid ammonia varies differently from that of free ammonia. Thus on the eastern side during the fall months the content varies from 0.028 to 0.050 parts per million. On the western slope the amount is greater, varying from a maximum of 0.118 parts per million in the north to one of 0.130 parts per million in the southern, W. 8 to W. 13, heavily wooded districts. During the winter there is a general decrease on the eastern side to almost one third of the above values. On the northern part of the western slope this is less marked, and in divisions W. 8 to W. 13 the variation is reversed and there is an increase to a maximum of 0.160 parts per million. In these regions of

heavy forest growth the amount of vegetable matter washed into the streams by the rains evidently overbalances the effect of the consequent dilution of the stream. In the spring there is an increase in the albuminoid ammonia in the streams on the eastern side to a value below that for the fall months, while on the west there is a decrease to a similar value, which is evidently the result of the thorough washing of the stream beds, and the absence of any amount of decaying vegetable matter, such as leaves, along the banks of the streams.

The maximum values for streams of classes "A" and "B" on the eastern side are: in the fall 0.050 parts per million, in the winter 0.025 parts per million (except in such a special case as the Corte Madera Creek, which has been discussed on page 50), and in the spring 0.030 parts per million. On the western side the values are higher; in the fall the northern streams may contain as much as 0.118 parts per million, and the southern 0.130 parts per million. In the winter the streams draining the heavily wooded regions, such as W. 8 to W. 13, reach a maximum of 0.160 parts per million. In these latter districts the amounts in the spring do not exceed 0.070 parts per million.

Disregarding the seasons, it may be stated that a stream of pure water in this area may contain as high as 0.050 parts per million of free ammonia, and 0.160 parts per million of albuminoid ammonia.

The streams known to be somewhat polluted and classed as "D" contained amounts of albuminoid ammonia in excess of the normal values that have been given. This was especially true during the fall months. At this time the presence of an excessive amount of albuminoid ammonia is a good indication of pollution, but after the winter rains the determination loses much of its significance. Thus the maximum during the fall on the eastern slope was given as 0.050 parts per million. Some streams graded "D" gave the following values, 0.118, 0.094, and 0.052 parts per million. In only one of these cases was the free ammonia above the normal value. The streams graded "C" generally showed somewhat abnormal albuminoid ammonia content and very rarely a somewhat high value for the free ammonia. The tendency was to give high albuminoid ammonia in the fall, followed by less than the normal decrease during the winter, and high or average content in the spring.

The springs examined are too few in number to admit of any reliable conclusions being drawn. They all gave the largest amounts of ammonia in the fall, and the lowest (with one exception) in the spring. The maximum values were 0.022 parts per million of free ammonia, and 0.074 parts per million of albuminoid ammonia.

The reservoirs vary somewhat among themselves, depending on how well they are cared for. Thus, for example, the Crystal Springs Lake

reservoir in the fall of 1908 showed a very much higher content of organic matter than in the fall of 1907. At the same time the statement was published in the newspapers that the owners had allowed the lake to become very dirty through neglect of the usual removal of the plant growths along the shores. Such a factor as this would overbalance any ordinary seasonal variation, and make comparison between cared-for and uncared-for reservoirs impossible. The data collected justify the following statements. The free ammonia should not exceed 0.030 parts per million under normal conditions. It is lowest in the fall, reaches a maximum during the winter, and decreases again in the spring. In a clean reservoir the albuminoid ammonia should not exceed 0.150 parts per million at any time; if the vegetable growth is unchecked the value may reach 0.250 parts per million. It is lowest in the spring, higher in the fall, and reaches a maximum value during the winter. The time of this maximum is the natural result of the addition of the vegetable matter, such as leaves, etc., carried by the streams at this time of the year.

NITRITES.

Small amounts of nitrites may be found in the streams at any season of the year, and may be regarded as insignificant. The amount should, however, not exceed 0.003 parts per million in the winter, or 0.001 parts per million at other seasons. A larger amount requires either some explanation such as would be given by abnormally high ammonia or nitrate contents, or assurance from the character of the watershed that pollution is out of the question. Even this small amount of nitrite is very rarely found during the fall or spring months, but a trace varying from 0.0005 to 0.002 may be regarded almost as a normal constituent during the winter. Streams graded "C" and "D" gave as high as 0.005 parts per million at varying seasons of the year. The almost invariable presence of free ammonia indicates that the process of decay induced by the "bacteria of nitrification" is actually taking place, and therefore a small amount of nitrite, since it is one of the transition products of this decay, is to be expected. Experience has shown that this amount is generally too small for detection, so that the presence of any detectable amount of nitrite in a stream, during the spring or fall months, may rightly arouse a suspicion as to the purity of the water which should require that direct evidence to the contrary be produced.

The springs examined which by their location were the least exposed to pollution did not contain any nitrites at any time. Two others showed rather large amounts. One, E. 4., B. No. 31 in the table, contained at the same time rather large amounts of nitrates, and the other, E. 6, C. No. 15

in the table, was not free from the possibility of direct pollution and contained distinctly abnormal amounts of nitrates. On the other hand another spring, W. 3, B. No. 47 in the table, contained a large amount of nitrate, but no nitrite.

In the case of the reservoirs the data are much the same as those for the streams. A quantity as small as 0.001 parts per million may be found at any season, but very rarely in the fall or spring, and is insignificant. In the winter the amount may reach 0.006 parts per million. A quantity in excess of this latter value should arouse suspicion.

NITRATES.

The streams do not normally contain any appreciable amount of nitrates during the fall months. In a few cases streams classed "A" or "B" showed as high a nitrate content as 0.15 parts per million on the eastern side, and 0.50 parts per million on the western. During the winter and spring months nitrates generally appear in those streams which contain none in the fall, and increase in the others. With a single exception nitrates above 0.75 parts per million were not found in any stream classed "A" or "B" at any time. The single exception was a stream on the northern part of the western slope (W. 3, No. 39) which showed a content as high as 2.0 parts per million. A spring in the same valley gave 2.7 parts per million nitrates with low ammonia and no nitrites. Both of these waters are distinctly abnormal. The surrounding country is wild and uninhabited, so that pollution is out of the question. It is of the same character as that of W. 2, 4, and 5, none of which furnished a similar case. The explanation must be sought in some abnormal underground condition.

The normal values for nitrates may be stated thus: in the fall, none, sometimes 0.15, and very rarely 0.50 parts per million. A trace of nitrate is a normal constituent during the winter and spring months, but the amount should not exceed 0.75 parts per million, and generally does not exceed 0.50 parts per million. An amount in excess of 0.75 parts per million may rightly be regarded with suspicion. The reverse of this, that polluted water will contain more than 0.75 parts per million of nitrates, does not hold, for waters graded "C" and "D" very rarely showed any abnormality in the nitrate content.

No reliable conclusion can be drawn from the data on the springs. Some gave higher values than others for no apparent cause. More than 2.0 parts per million at any season should certainly be considered suspicious.

The data on the reservoirs are more satisfactory. Here the normal conditions are the same as those for streams, namely no nitrates in the fall, and an amount not exceeding 0.75 parts per million during the winter and spring. This absence of nitrates in the fall is the natural result of their absorption by growing vegetation, for during the rainless summer months the fresh supply from streams is either completely cut off or very much curtailed.

CHLORIDES.

The discussion of the data concerning the chlorides will necessitate the consideration of each watershed separately, with regard especially to the local meteorological conditions, before a summary of the results is attempted. One point, which is of pronounced and general application, may well be considered in advance, namely the seasonal variation. This factor is of great importance in this region. As has been mentioned* the climate is characterized by a long, rainless summer, during the greater part of which strong winds, the "trade winds," blow regularly day after day from the northwest, over the ocean, and towards the land. These winds very often carry with them a bank of heavy fog and spray, whose progress eastward is more or less checked by the ridge of mountains running the length of the peninsula. As a result the western slope is exposed to sea-wind and sea-fog conditions which are extreme in character. These winds sweep over the ridge of mountains, concentrating with a funnel-like effect in the lowest saddles,† and sometimes carry the fog with them, and spread it in a fan shaped bank over the upper part of those eastern watersheds which head near such a pass. Thus the eastern watersheds are unequally exposed to the effect of this sea fog. The warm air of the valley prevents the progress of the fog eastward to any great extent, and a low ground fog in the valley is almost unknown. More often a high fog collects over the valley during the night, but this is usually dispelled a few hours after sunrise. These wind and fog conditions are peculiar to the summer months.

At the same time the climate is characterized by a practically complete absence of rain. The very rare summer shower is so quickly absorbed by the dry ground and vegetation, that its effect may be neglected. This absence of rain causes a very marked shrinkage in the streams, amounting generally to the drying up of the greater part of their lower courses, and sometimes to their complete disappearance. The same

* Page 9.

† These saddles, and the resulting wind currents, are indicated on the map with small arrows.

cause effects considerable concentration of all the water, stream and catchment reservoir, with a consequent increase in the chloride content. In the fall, the first rain is generally absorbed in the ground, and has little or no effect on the streams and reservoirs. When the heavy winter rains come, they introduce two factors. The rinsing of the watersheds and stream beds, and the dilution of the streams and reservoirs. This rinsing effect is not shown by any of the data, in every case a drop in the chloride content indicates the preponderating influence of dilution. Here again a marked difference between the streams on the eastern and western slopes is noticed. On the eastern side the influences which have been described apply with full force, on the western they are modified. In general it is true that the western streams are larger, and more constant in their flow, than the eastern. The moisture carried to their watersheds by the fog which has been described, as well as the dense forest growth in the southern part of the area, both counteract the concentrating effect of the rainless summer months. Moreover in the heavily wooded regions the rain water runs off much more slowly, and the diluting effect is less marked. As a result of these factors a less pronounced difference in the chloride content of the western streams between fall and winter is to be expected, and was actually found to be the case. The above differentiation between the eastern and western streams is a general one to which there are a few exceptions. The southern part of the eastern slope resembles in character that of the western, and the data reflect this similarity. In the same way the northern part of the western slope approaches in character to that of the eastern and affords corresponding data.

In the spring, before the beginning of the "dry" season, the contents of all the waters examined are intermediate between those of the winter and fall. These peculiar climatic conditions, which are characteristic to a greater or less degree of the whole Pacific coast of California, should be borne in mind when these data are compared with those of Eastern states. In the latter, where there are no distinct "dry" and "rainy" seasons, the variation between fall and winter is very much less pronounced, and is probably negligible. This seasonal variation introduces a factor which makes the construction of "isochlors" in the usual sense of the word impossible; for in this climate they can only indicate an average value, which must be modified according to the season. At the same time the importance of the study of local conditions, and the establishment of local standards for all seasons is greatly emphasized.

The subdivisions will next be considered separately, beginning on the East and proceeding from North to South, and then dealing with those on the western slope in the same order.

CHLORIDE CONTENT OF EACH SUBDIVISION.

E. 1.—The division E. 1 includes all the territory east of the main ridge from the northern boundary of the field of this investigation, at Baden station, southward to the watersheds of San Andreas Lake and San Mateo Creek. This large area contains no important streams, none that flow at a time other than immediately after a heavy rainfall. The main ridge is low at the northern end, approximately 700 feet high, and the trade wind sweeps over it with almost unchecked force.

The ground is broken into irregular rolling hills and valleys, all exposed to wind and fog. Among these hills are a number of small ponds which are fed partly by rain water and partly by springs. The surrounding fields are used for the pasturage of cattle in connection with several dairies. High chlorides and high organic matter would therefore be expected in the pond waters. The data collected confirm this inference. One of the largest ponds showed chlorides amounting in parts per million to 44.74 in the fall, 31.72 in the winter, and 37.64 in the spring. Two smaller ones gave in the spring 86.67 and 23.97 respectively. The former gave evidence of pollution and was graded "D," the latter was simply an accumulation of rain-water, and dried up early in the summer. The significant data are those given for the large pond, which show an average chloride content of 38.03 parts per million.

E. 2.—The division E. 2 includes San Andreas Lake and the surrounding hills whose streams drain into it. This lake is formed artificially by a dam at the southern end which impounds the water of a stream originally flowing towards the southeast. The resulting valley is protected on the west by the main ridge, which reaches an altitude of 1000 feet, but is exposed to the winds from the northwest. During the summer the trade wind sweeps through the valley with considerable violence, and carries with it some fog and spray. In addition to the waters flowing naturally into it, the lake is supplied through artificial flumes and tunnels with water from Lake Pilarcitos and from Stone Dam, both in W. 7. It is drawn upon continually as a part of the San Francisco water supply system. The chlorides found were in parts per million in the fall 23.33, in the winter 19.36, and in the spring 21.70. The average value is 21.46 parts per million. The average of the added water for Lake Pilarcitos is 19.19 parts per million, and of the much smaller volume from the Stone Dam is 24.21 parts per million. The average value for San Andreas, which is lower than those to the south as well as to the north of it, must be considered as accounted for, at least in great part, by this dilution with water of relatively low chloride content.

E. 3—The division E. 3 includes the watersheds and tributaries of San Mateo Creek. This stream rises in the hills to the west of E. 2, and originally flowed southeastward to a point, southwest of San Mateo, where a break in the chain of low hills between its course and the bay afforded an outlet northeastward. At this pass in the hills a very large dam was constructed in connection with the San Francisco water supply system, which resulted in the formation of Crystal Springs Lake. This latter is now a narrow, deep body of water some five miles long. It is supplied by San Mateo Creek and another small stream flowing from the north, by large amounts of rain water from the extensive watersheds to the north, west, and south, and by springs along its bottom. An inspection of the map will show the striking alignment of the San Bruno pond, San Andreas Lake, Crystal Springs Lake, Searsville Lake, and the ponds along the Los Trancos ridge, all following an old fault line which is now characterized by a large number of springs along its whole length. The northern two-thirds of the watershed is rigidly patrolled by the owners, and, with the exception of a few negligible keepers' houses, is absolutely uninhabited. To the southwest the watershed is crossed by three county roads, one of them much travelled, and along which a number of ranches are located. Pollution from these sources is not impossible, but the probability is so remote as to be negligible, especially when the long storage of the water in the lake is taken into account. Although the mountains to the west reach an altitude of a thousand feet, the valley is nevertheless exposed to the winds from the northwest. The greater distance from the ocean, as well as the better protection given by the mountains, lessen materially the amount of fog and spray carried with the wind. On the western boundary of the watershed and near the southern end, there is one of the saddles (altitude about 800 feet) which have been referred to.* The ocean to the west approaches the ridge at this point (Half-Moon Bay) and the winds sweep up the valley formed by Pilarcitos Creek, and through this pass, with considerable violence.

Chloride determinations were made in this division with the following results: On San Mateo Creek, some three miles above the inflow into the lake, a small seasonal variation with an average content of 21.50 parts per million was found. A mile further down, in the spring, 23.04 parts per million; on the tributary to the east, a stream dry from late spring to winter, 25.35 parts per million were found after a heavy rainfall. In the lake itself, near the dam and the intake of the pipe line, the amounts in parts per million were, in the fall 26.30, in the winter 22.59, in the spring 25.36, in the fall again 26.30. The average is 25.14 parts per million. A sample from the creek below the dam, carrying the drainage from the keeper's house, barns, etc., gave in the fall 41.1 parts per million.

* Page 53.

E. 4—Division E. 4 consists of the region between the foothills and the bay from Belmont to Menlo Park. It contains no streams that carry more than rain water during the winter, a catchment reservoir at Belmont, and a number of springs in the foothills. The reservoir at Belmont is somewhat exposed to pollution from the ranches on the watershed. It was sampled once, in the fall, and showed a chloride content 56.5 parts per million. A spring in the hills southeast of Redwood City, located in a cattle pasture and inadequately protected, gave a small seasonal variation and an average of 14.19 parts per million.

E. 5—The division E. 5 is one of the largest, and has the most complex drainage system, of any in the territory under investigation. The length along the main ridge is some eleven miles, the width between the ridge and the foothills is from three to four miles. The height of the ridge increases from 2200 feet at the northern end to a maximum of 2555 feet at the southern; a little further south is Black Mountain with an elevation of 2787 feet. Along this ridge there are three saddles: One with an elevation of about 2000 feet at the northern end, at what is locally known as King's Mountain House; a second, very near the middle, with an elevation of 1680 feet; and the third at the southern end, with an elevation of about 2000 feet, and located between two peaks of 2555 and 2787 feet elevation respectively. The ocean winds sweep over the land west of the ridge with unbroken force, and are concentrated, funnel-fashion, at each of these saddles. At these points the fog and spray are carried over the ridge line, and spread out, over the upper parts of the neighboring watersheds. During the summer months this fog condition is of almost daily occurrence, and must be considered as an important factor in influencing the chloride contents of the adjacent streams.

There are three distinct streams in this division, each with a number of tributaries, and all flowing eventually into the San Francisquito Creek and hence into the bay. The middle system consists of the Corte Madera Creek, its tributaries, and the small mountain streams as far northward as Bear Creek. All these streams flow together at Searsville, where a large dam impounds them. At the height of the rainy season a large amount of water flows over the dam, otherwise the only outlet is through the pipes of the Stanford University water system. North of this system Bear Creek, West Union Creek, and a few small tributaries first unite and then join the San Francisquito Creek just below the Searsville dam. The largest of these, and the only one that generally flows throughout the year, is Bear Creek, but the greater part of its water is collected by a dam near the point where the stream enters the valley, and is diverted

through a pipe line into an artificial reservoir known as "Bear Gulch" or "Menlo" reservoir. A small amount of water flows down the upper part of the West Union Creek channel during the greater part of the year. The third, southern, system is composed of Los Trancos Creek and its tributaries, and enters San Francisquito Creek about two and a half miles below the Searsville dam.

The watershed of the northern, Bear Creek, system is exposed to the ocean winds coming through the saddle at King's Mountain House. Samples from a good sized stream, unquestionably pure, showed a normal seasonal variation and an average value of 18.09 parts per million of chlorides. Another mountain stream, sample in the winter, gave 15.67 parts per million. Bear Creek, at the diverting dam, gave an average of 18.99 parts per million. In the "Bear Gulch" reservoir the average was 20.04 parts per million. West Union Creek, known to be somewhat polluted, gave an average of 28.66 parts per million. Just above its junction with San Francisquito Creek the chlorides in the fall were 63.6 parts per million, and after heavy rains the more normal value of 18.9 parts per million.

The abnormal conditions existing in the bed of Corte Madera Creek have been described on page 50. In the upper part of the stream the average was 26.98 and from the lower, below possible sources of pollution, it was 38.14 parts per million. Two small streams well up on the watershed gave, in the winter, values of 15.58 and 14.75 parts per million, and down in the valley below several ranches, the main stream showed, in the fall, 41.5 parts per million. This watershed is exposed to the effects of the southern saddle described on 57. The fog appeared to cross the ridge at this point as often, if not more often, than at any other point. In Searsville Lake the average chloride content was 30.75 parts per million.

The Los Trancos watershed is somewhat less exposed, as it is separated by a ridge of Black Mountain from this southern saddle. Along this ridge are located a number of ponds, whose position in a line with Searsville, Crystal Springs, and San Andreas lakes has been noted on page 56. The largest of these ponds gave an average chloride content in the winter and spring of only 9.40 parts per million; another, in the spring, 13.52; a small stream flowing from a spring nearby, an average of 14.16 parts per million. The creek itself, above possible pollution gave an average value of 18.78, and below possible pollution, 27.90 parts per million.

E. 6—The subdivision E. 6 is a small, hilly area, drained by Madera Creek. The stream is dry in the late spring and fall, and is obviously polluted at all times by the drainage from a number of ranches along its

course. The area is further characterized by the presence of a large number of springs. Five of these, sampled in the winter, gave chloride contents varying from 14.38 to 28.20 parts per million. The average from the three seasons of one of them, graded "C," was 20.77 parts per million.

E. 7—The division E. 7 is the one drained by San Antonio, or "Adobe" Creek. The watershed is well protected by Black Mountain from the effect of the trade winds, and the upper part of the stream carries a good flow of water throughout the year. Sampled above any possible source of pollution an average value of 17.23 parts per million was found, and tributaries gave corresponding values for their chloride contents.

E. 8—Subdivision E. 8 consists of the two forks of Permanente Creek and their watersheds. They are both well protected by Black Mountain from the wind and fog. The northern is almost dry except in mid-winter. A tributary stream flowing from a spring well up the side of the mountain gave an average chlorine content of 12.68 parts per million. The southern fork flows the year through unless the summer be exceptionally dry. Above any possible pollution the average chloride content was 16.35 parts per million, with a very small seasonal variation; a tributary of the same character gave 16.29; further down, below a little cultivation, the average was 19.54, and in the valley, below obvious pollution, it was 35.59 parts per million.

E. 9—Stevens Creek, whose watershed is subdivision E. 9, is one of the larger streams on the eastern slope. It rises near the summit of Black Mountain, on the southern side, and near the southern saddle described on page 57 where the division E. 5 was described. The course is at first southeastwards for about three miles. The watershed is formed by a valley between the main ridge, which here has an elevation of about 2500 feet, and Monte Bello ridge. The latter starts at the summit of Black Mountain at an elevation of 2787 feet, but descends to about 1500 feet at a point some three miles to the southeastward. This valley is parallel to, and in line with, the valleys described in division E. 2, E. 3, and E. 5. At the summit it is exposed to wind and fog, but otherwise it is well protected by the main ridge. At a point about three miles southeast of Black Mountain the valley is crossed by Table Mountain (elevation about 2000 feet) and the stream is turned northeastward. After flowing about two miles in this direction, around the end of Monte Bello ridge, the stream reaches the open valley. Beyond this the stream bed is dry from late spring till late fall, but during the winter it runs almost due north to San Francisco Bay.

The headwaters, a tributary at Table Mountain, and the lower stream near the valley were sampled at the three seasons, and fall samples

for chlorides only were taken along the whole course of the stream and from many of its tributaries. For the upper part of the watershed values for the chloride content between 13.82 and 17.70 parts per million were found. In the lower stream, below possible pollution, the content was as high as 25.63 parts per million.

E. 10—The subdivision E. 10 is a small one of little importance. It consists of the area between E. 9 and E. 11, which is drained by a stream, Calabazas Creek, which is dry for the greater part of the year. The mineral springs known as "Azule Springs" are located on the upper part of the watershed. A sample from the creek in the fall, below possible pollution, and just above the point where the stream disappeared, gave 28.58 parts per million of chlorides.

E. 11—The area designated E. 11 is a large one, and consists of the watersheds drained by Campbell Creek and its tributaries. The main ridge (elevation from 3000 to 2500 feet), runs northwest and southeast, the creek almost due northeast from the ridge to the bay. This division, as well as the next two, E. 12 and E. 13, have some of the characteristics of those on the western slope as has been pointed out on page 54. They are much larger than those which have been considered, the watersheds receive a very much larger rainfall, are more heavily wooded, the streams are larger, and except in their lower courses in the valley, flow throughout the year. The watersheds are well protected from the ocean fogs and winds. This protection is afforded by their much greater distance from the ocean, and by the ranges to the west of the main ridge. A storage reservoir located in the mountains on the line between E. 11 and E. 12, gave an average chloride content of 9.44 parts per million with a very low seasonal variation. The streams above possible pollution showed the same small seasonal variation, and gave average values for the chloride content of 13.05, and 10.96, parts per million; below possible pollution the chloride content was about five parts per million greater.

E. 12—The conditions which have been described for subdivision E. 11 apply also to E. 12, the region drained by Los Gatos Creek. In this latter case the area is larger, and the stream flow greater. The watershed is however inhabited, ranches are scattered over the whole area, and no samples from streams classed "A" were obtained. The chlorides in a number of streams graded "B" varied from 10.14 parts per million in the winter to 16.61 in the fall.

E. 13—Subdivision E. 13 is a large area, drained by two forks of the Guadalupe River. Only the western fork was included in this investigation. The conditions are similar to those described for E. 12, except that the upper part of the watershed is uninhabited and this stream may be

classed "A." Here the average chloride content was 10.25 parts per million, a "C" grade tributary gave on the average 11.99 and the main stream below probable pollution the average of 22.64 parts per million.

W. 1—Subdivision W. 1, on the western slope, is so exposed to sea winds, fogs and spray that the conditions are distinctly abnormal. The distance from the ocean to the ridge is short, the hills are bare, wind-swept pastures. The streams are small, and flow only during the winter. Two streams and two springs were sampled, and the chlorides varied from 41.8 parts per million in the winter to 62.02 parts per million in the fall. The seasonal variation in a stream was twelve, and in a spring was six, parts per million.

W. 2—Subdivision W. 2 is more important, as it consists of the watershed drained by San Pedro Creek and its tributaries. This stream has a fairly large flow the year through, and consequently the seasonal variation in the chloride content is very much smaller.* The watershed is uninhabited, and is protected on the south by a high ridge of mountains (elevation 1000-1500 feet) and on the north by the hills separating it from W. 1. The chloride contents are among the lowest found on the western slope, and range between 21.80 and 28.80 parts per million.

W. 3—In subdivision W. 3 are grouped a number of small independent streams and their watersheds. They are all very much exposed to the ocean winds and fogs; those in the southern rather more so than those in the northern part. The samples showed a somewhat abnormal seasonal variation. The stream at Green Canyon averaged 42.11 parts per million, that at the "Italian ranch" 25.69, a spring at the same place 30.56, and San Vincent Creek, graded "C," 40.96 parts per million.

W. 4—The watershed of Deniston Creek and its tributaries forms the subdivision W. 4. The stream is a large one, but slightly exposed to pollution above the points of collection of the samples by several ranches and irrigating systems. A sample further up the stream was not obtained. At this point, graded "B," the average chloride content was 33.10 parts per million, and the value in the spring was seven parts higher than in the fall.

W. 5—The subdivision W. 5 includes a group of small independent streams and their watersheds. None of them carries any large amount of water. Only one was sampled, and, in the fall, a chloride content of 79.2 parts per million was found. At this time the stream was very low,

* As has been pointed out on page 54, the greater rainfall on the western slope as compared with the eastern, results in a correspondingly smaller seasonal variation throughout the area.

so that the high value may be due to the season, and is probably not normal.

W. 6—The area drained by Frenchman's Creek defines subdivision W. 6. This is a large stream, with a good flow throughout the year. The watershed is rather long and narrow, and is somewhat protected from the ocean winds by the surrounding hills. Sampled at the diverting dam of an irrigating system an average chloride content of 27.27 parts per million, and the small seasonal variation characteristic of the western slope, were found.

W. 7—The watershed of Pilarcitos Creek and its tributaries forms division W. 7. The stream rises in the mountains between E. 3 and W. 4 and W. 6, and is impounded by a dam, forming Pilarcitos Lake. This part of the watershed is exposed to the ocean winds from the northwest. As has been stated on page 55, the water from the lake is run into San Andreas Lake through tunnels and flumes. The average chloride content of the lake water was 19.19, and of a small tributary from the south flowing into the lake through a flume 23.23 parts per million. Below this dam the stream flows through a narrow valley, is fed by numerous small tributary streams and springs, and is impounded again at Stone Dam. Here the water is again diverted into San Andreas Lake. The average chloride content of the water at Stone Dam was 24.21, and of a small tributary spring nearby 29.56 parts per million. Below this the stream flows on through a narrow valley with considerable forest growth to a point northeast of the town of Half Moon Bay, where it turns to the southwest and runs into the ocean. At this turning point the average chloride content was 37.45 parts per million. A tributary stream below this, sampled in the fall and above possible pollution, gave 27.85 parts per million. Another tributary several miles to the south, draining an inhabited valley and graded "D," gave 42.41 parts per million of chlorides in the fall.

W. 8—Subdivision W. 8 is one of the group which contains thick forest growth. It is drained by Purisima Creek and its tributaries. A spring near the ridge, just west of King's Mountain House, showed an average chloride content of 14.02 parts per million. The stream itself, sampled in fall and spring only, gave an average of 28.53, and a small tributary, sampled in the spring, 21.52 parts per million of chlorides. After the inflow of a large tributary somewhat exposed to pollution the chlorides in the main stream were 33.19 parts per million in the fall.

W. 9—The subdivision W. 9 is a small one drained by Lobitos Creek. The watershed is bare pasture land, with little or no forest growth. The chlorides in the fall were 135.5 and in the spring 120.0 parts per million.

These very high values are not sufficiently accounted for by the possibility of slight pollution from one or two ranches, and from the cattle pastures, as other streams draining very similar country do not show any such high chloride contents.

W. 10—The region drained by Tunitas Creek and its tributaries forms subdivision W. 10. Only the main stream, above all possibility of pollution, was sampled; and here the average chloride content was 46.70 parts per million.

W. 11—The subdivision W. 11 is a very large one, and consists of the entire region drained by San Gregorio Creek and its many tributaries. It is for the most part densely wooded with heavy forest growth, is not especially exposed to the ocean winds, and possesses those characteristics which have been described on page 54 in the discussion of the group W. 8—W. 13. The following data were obtained from samples taken from tributaries. Harrington Creek, sampled winter and spring only, gave an average chloride content of 49.60 parts per million; a small stream tributary to La Honda Creek (three samples), a value of 29.51; La Honda Creek further down, graded "C," 39.62; and Alpine Creek, graded "C," gave 30.15, all expressed in parts per million.

W. 12—No samples were obtained from subdivision W. 12. It consists of a small area drained by Pomponio Creek.

W. 13—The extensive area drained by Pescadero Creek forms subdivision W. 13. This stream is the largest on the western slope, and flows throughout the year. The watershed is very heavily wooded with dense forest growth and has those characteristics of the western slope which have been described on pages 49 and 54. Samples taken from the streams above all possibility of pollution gave an average value of 43.71 parts per million of chlorides. A tributary, Peters Creek, gave the distinctly higher value of 51.16 parts per million. Its watershed is less heavily wooded, and its situation on the western side of the main ridge exposes it to the ocean winds which blow up the valley. About three miles further down the main stream, above any possibility of appreciable pollution, the average chloride content was 38.66 parts per million. At the town of Pescadero, above the main bridge over the stream, the chloride content in the fall was 49.9 parts per million.

The values obtained for the chloride contents have been plotted on the accompanying map of the peninsula. The average of the values obtained at the three seasons has been used. When data for one or two seasons only had been collected, the average value was estimated, on the basis of the seasonal variation at neighboring points. These estimated values are given in round numbers, and are enclosed in parentheses on the

map. Curves, "isochlors," were then drawn through the points of equal chloride content. With the exception of a few springs, and two streams, these curves indicate the normal chloride values very satisfactorily. Six samples from streams, evidently polluted, or obviously affected by some abnormal condition, were omitted altogether.

The map brings out clearly the remarkably large variation in the normal chloride content within a comparatively short distance. Two important factors are emphasized, namely rainfall and sea winds.

The resemblance between the paths of the lines of equal chloride content and of equal rainfall is striking. The region about Lake Pilarcitos, which has the restrictedly high rainfall of fifty inches, has the lowest chloride content within fifteen miles. San Pedro Creek, which drains this region on the north, has the lowest chloride content found on the western slope. Southwards, where the rainfall decreases, the chlorides increase, until another region of high rainfall is encountered. Here, again, the chloride content decreases. In the southern district the lines of equal chloride content do not coincide so closely with those of equal rainfall as they do in the northern region. This may be due to two causes: First, the sheltering effect of the mountains, which would tend to displace the low value "isochlors" to the eastward; and, second, incomplete data. The region to the south and southwest of Black Mountain is uninhabited and not easily accessible. When data in this district have been obtained the low "isochlors" may be deflected more to the southwest, towards the point of maximum rainfall.

Superimposed on this rainfall factor is that of the sea winds. The effect of this latter is both general and local. The general effect is seen in the difference between the lowest chloride contents in the regions of highest rainfall. Around Lake Pilarcitos, rainfall fifty inches, the lowest chloride found was nineteen parts per million; around Black Mountain, rainfall thirty-five inches, the lowest is fourteen parts per million, and south of Los Gatos, rainfall about forty inches, the lowest is ten parts per million. This general decrease in the chloride content from north to south may be considered to be the result of the more complete shelter from the sea winds afforded by the main ridge.

This "sea-wind" factor is especially prominent locally at the following points. In the San Pedro Valley the "isochlors" are deflected to the southeast, against increasing rainfall; here the sea winds sweep up the valley with unchecked force. North of San Andreas Lake, division E. 1, the "isochlors" are deflected away from the ocean. This region is especially exposed to the ocean winds and spray. In the valley west of Half Moon Bay the "isochlors" recede from the ocean; here again the ocean

winds sweep up the valley and over the pass described in considering division E. 3. The same effect is noticed in the San Gregorio Valley, and its absence is marked in the case of the Pescadero Valley where a high range to the north affords protection. On the eastern side an instance is seen at the head of Corte Madera Creek, northwest of Black Mountain. This is at the "southern pass" described on page 57, division E. 5, and the marked deflection of the "isochlors" is apparent.

A little further north a pinching together of the two sides of the twenty parts per million "isochlor" at the point of the lowest, middle pass of division E. 5 is apparent. South of this the general protection afforded by the main ridge eliminates any local effect.

It will be interesting to note whether, as work of this character is extended to larger regions along the Pacific coast, the general influence of the rainfall, and the general as well as local influence of the sea winds, retain the position of prime importance which is indicated by this investigation.

HARDNESS.

As a class all the waters sampled were very hard. This is not a local peculiarity, but is generally true of all the waters of the Western states.

The total hardness varied irregularly with the seasons, but was often highest in the fall, lowest in the winter, and intermediate in the spring. On the eastern slope the total hardness was generally between two hundred and two hundred and fifty parts per million (expressed in terms of calcium carbonate), for streams, and between fifty and one hundred and twenty for reservoirs. On the northern part of the western slope the total hardness was less, sometimes as low as thirty parts per million, but increased in the southern part to about the same values as on the eastern side. The springs were generally low in total hardness. The temporary hardness likewise varied greatly. The general range for streams was from one hundred and fifty to two hundred and fifty parts per million (expressed in terms of calcium carbonate); it was lower in reservoirs (40-120), lower in the streams on the northern part of the western slope, and lower in springs. The permanent hardness ranged in general from twenty to fifty. It was lower in the reservoirs, higher in the streams on the northern part of the western slope, and higher in the springs. Free alkaline carbonates appeared in waters from different sources at irregular intervals. The amount seldom exceeded thirty parts per million.

TOTAL SOLIDS.

The total solids were on the whole high. In streams the value was

generally between two hundred and three hundred parts per million. Those in the southern part of the western slope gave as high as four hundred to five hundred parts per million. Springs and reservoirs were generally between one hundred and two hundred parts per million. The high values for total solids as well as for hardness, as compared with Eastern waters, are due to the influence of the same factors that bring about the high chlorides, namely the smaller rainfall, and the long summer period of weathering with little washing away of the resulting materials.

WELLS.

Samples were collected from fifteen deep wells on the floor of the Santa Clara Valley. These are typical of the large number which provide the water supply of this relatively thickly populated region. They all lie in a belt which follows the shore of the bay and are from one hundred yards to two miles distant from the marsh line. All are bored and cased wells of considerable depth, that is from one hundred to five hundred feet. They are abundantly supplied from underground sources, but their relation to the streams of the peninsula is as yet somewhat uncertain. The wells are "artesian" in the sense that, if not drawn upon too heavily, the water flows out of the top of the boring with considerable force. The data obtained are not considered sufficient to warrant the drawing of any important conclusions, and it is the intention of the writer to extend this work in this direction in the future. The results are summarized in the following paragraphs.

Many of the wells contain large amounts of free ammonia. The values obtained varied from none to 0.228 parts per million. The albuminoid ammonia results were lower, varying from none to 0.080 parts per million. No fixed relation between the two ammonias could be observed, nor did the absence of the one coincide with the presence or absence of the other. Nitrites were generally absent, and not often over 0.005 parts per million. One well, from which five samples extending over one year were taken, gave an average of 0.021 parts per million. Their presence at all seasons seemed characteristic of certain wells, and their absence of others. Nitrates were generally absent, but appeared regularly in certain wells. The amount was generally below 0.50 parts per million, the maximum was 1.40 parts per million. The chloride content varied widely, the range being from fifteen to two hundred and fifty-eight parts per million. Omitting the three highest values the range was from fifteen to forty parts per million. As pollution seems out of the question in wells of this class the explanation of the high chloride content must be sought in

either the source of the water, if it can be determined, seepage through marine deposits, or infiltration of salt water from the bay. The wells in the southern part of the field showed the lowest chloride contents; with an average of between fifteen and twenty parts per million.

The water from most of the wells was very hard, the total hardness being generally about two hundred parts per million, and the temporary only a little less. The highest permanent hardness was 25.3 parts per million. Free alkaline carbonates were common (found in fifteen out of twenty-five samples analyzed) and were generally between forty and seventy parts per million. Well No. 12 was abnormal and contained: temporary hardness 77.2, free alkaline carbonates 146.0 parts per million expressed in terms of calcium carbonate. The total solids were high, ranging from 264 to 688 parts per million.

The seasonal variation was apparent, but small. The free and albuminoid ammonia, and nitrites, varied irregularly. The nitrates, in those wells which always contained a small amount, were highest in the winter. The chlorides decreased in the winter to about two parts per million below the fall values, and increased a corresponding amount in the spring. The total and temporary hardness generally increased a little during the winter months, while the permanent hardness and free alkaline carbonates fluctuated irregularly. In the winter the total solids were a little higher than during the fall and spring.

SUMMARY.

The object of this investigation is to determine the normal constituents of the potable water of the San Francisco peninsula, from a sanitary point of view, and before the growth in the population affects too seriously the natural purity of the water supplies. The significant constituents, and the interpretation of water analyses, are discussed briefly. The area studied included approximately six hundred and seventy-five square miles lying south of Baden station on both sides of the peninsula. This was divided into twenty-six subdivisions, thirteen on each side. The characteristic topographical and climatological features of the region are described in detail. Especial emphasis is laid on the distribution of the rainfall, the presence of the strong ocean "trade winds," both of which are peculiarly characteristic of the Pacific coast of California, and on the resulting, very marked, seasonal variation in the constituents of all the waters.

A careful, personal, survey was made of each watershed, and the points of collection were chosen with especial regard to the importance of

obtaining as nearly unpolluted water as possible. The sources sampled were classified in the field according to their probable purity. The sampling and the analytical work were done by the writer personally in accordance with the standard methods in general use. Since the usual phenol sulphonic acid method for the determination of nitrates was known to be unsatisfactory in the presence of large amounts of chlorides, a special study of the methods available for this determination was undertaken.

The detailed results of this study of the availability of the phenol sulphonic acid method, of the reduction method, and of their relative efficiency are given, and lead to the following conclusion. "For waters containing large amounts of chlorides the nitrogen present as nitrate may best be determined by the 'reduction method,' using the copper-zinc couple and oxalic acid. If the result of the determination indicates a nitrogen content in excess of five parts per million, the determination should be repeated, using the phenol sulphonic acid method, and standards prepared according to Mason's suggestion." With low nitrates the error may be as much as ten per cent, with twenty parts per million or over the error should not exceed three per cent.

The analytical data obtained from two hundred and forty samples are given in a table. These samples were taken from one hundred and twenty-six points of collection, from fifty-three of which at least three samples at the three characteristic seasons of the year, namely fall, winter, and spring, were collected. Of these samples one hundred and three were analyzed for chlorides only. In addition thirty-three samples were collected from fifteen deep wells, of which eight were analyzed for chlorides only. A map is given, on which are shown the several watersheds, the subdivision numbers, the points of collection, and the laboratory number of a sample from each point of collection. The analytical results obtained for each constituent are considered separately.

The turbidity, sediment, color, odor, and change of residue on ignition are found to be of minor importance in dealing with this class of waters, and without influence on the more important constituents.

The free and albuminoid ammonias varied both in quantity and in type of seasonal variation with the character of the vegetation on the watersheds. The extreme values at any season or on any watershed that should be passed without suspicion are set for free ammonia at 0.050 and for albuminoid ammonia at 0.160 parts per million in the case of streams. For clean reservoirs the limits are 0.030 for free, and 0.150 for albuminoid, ammonia. The data for springs are not conclusive.

Nitrites were generally absent, especially in the fall and spring

months. The maximum values, in the winter are, for streams 0.003, and for reservoirs 0.006 parts per million. The small number of springs examined did not afford conclusive data. Only small amounts of nitrates were found in any but exceptional waters. The normal values for streams are, in the fall, none, to 0.15, in the winter and spring a trace to 0.75 parts per million. The data for reservoirs lead to the same conclusions, and for springs are not conclusive.

The chlorides were determined with especial care, and the results obtained in each subdivision are treated separately, and the influence of local conditions is emphasized. Samples were collected from one hundred and twenty-six points of collection. From fifty-three of these points at least three samples at the three characteristic seasons of the year, namely, fall, winter and spring, were taken. The results show the exceedingly high chloride content of these waters as compared with those of the Eastern states. The normal values ranged, according to geographical location, from ten to fifty parts per million. This high chloride content is characteristic of the waters of the Pacific coast, and is due to the influence of two factors, namely the rainfall and the ocean winds. The rainfall is in general much less than that of the Eastern states, is almost entirely confined to the winter months, and leaves a long summer period with practically no rainfall, and consequently no washing or rinsing of the ground. The ocean winds are far greater in force and frequency than any met with in the Eastern states. The "trade winds" blow over the ocean from the northwest day after day, with clock-like regularity, throughout the summer months, and with considerable violence. The regularity and force of these winds is shown by the marked bending towards the southeast of the oak trees growing in the more exposed places. These winds carry to the land ocean fogs, and large amounts of salt in the form of impalpable dust, the product of the evaporation of the spray thrown into the air by the "white-caps" and the long, unbroken line of heavy surf. The results of the analyses were mapped, and "isochlors" were drawn. These curves coincide satisfactorily with the data collected, and show clearly the general influence of the variation in rainfall, and the general as well as the local influence of exposure to the sea winds. The seasonal variation was found to be great, and to vary with local conditions. The highest values occur in the fall, the lowest in the winter, and the intermediate in the spring.

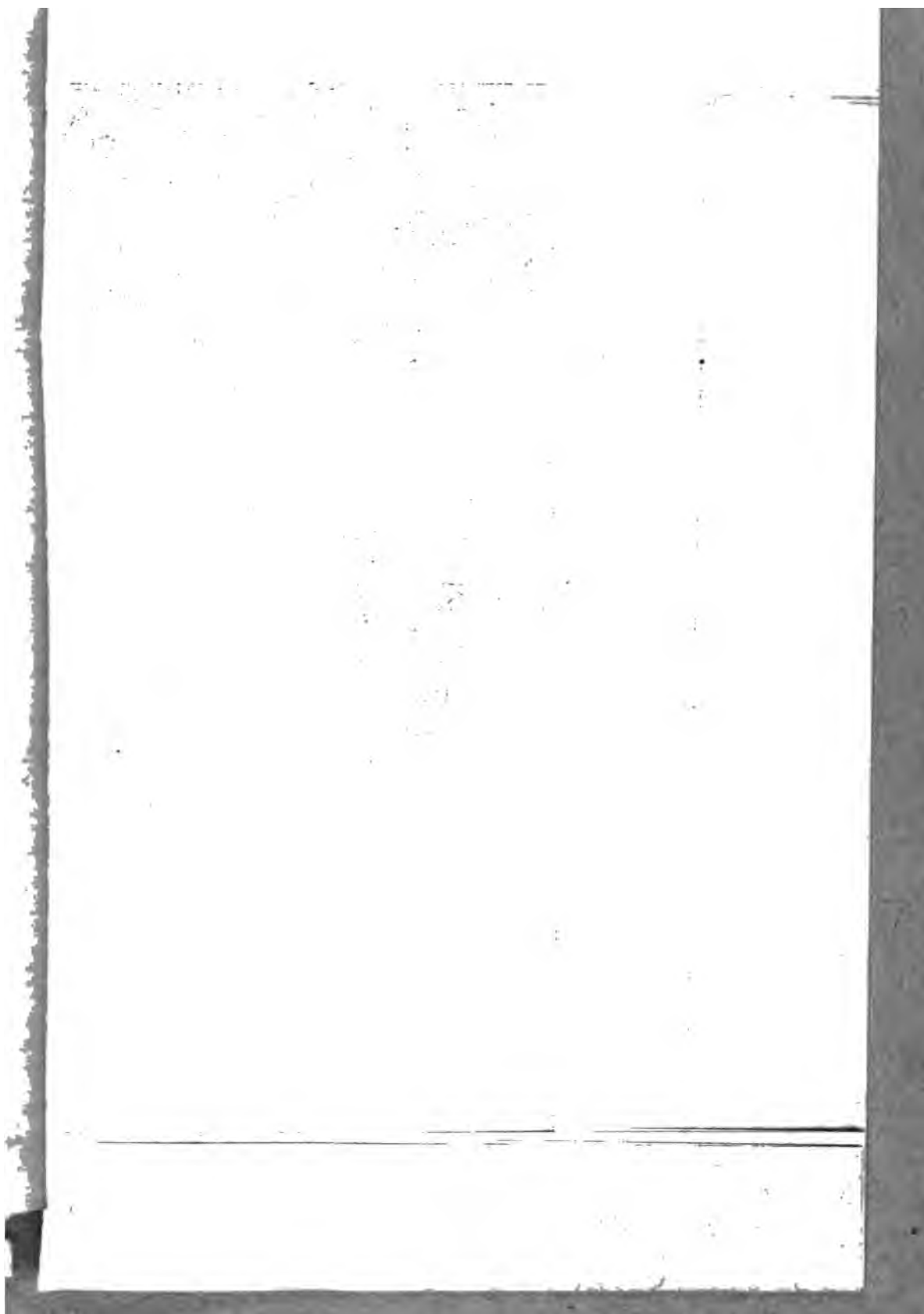
The waters were all very hard; as much as two hundred and fifty parts per million in streams and one hundred and fifty in reservoirs was not uncommon. The temporary hardness varied from one hundred and fifty to two hundred and fifty parts per million in streams and from

forty to one hundred and twenty in reservoirs. The permanent hardness was lower, seldom over fifty parts per million in streams, and less in reservoirs. Free alkaline carbonates appeared in all classes of waters at varying seasons, but the amount rarely exceeded thirty parts per million. The total solids ranged between two hundred and four hundred parts per million in the streams, and between one hundred and two hundred in the reservoirs. The springs were between the limits for streams and reservoirs. These high values are due, as has been pointed out in the case of the chlorides, to the relatively small rainfall, and long rainless summer period of weathering without any washing of the surface of the ground.

The data on the wells are discussed separately, and are considered to be inadequate. It is hoped to supplement them in the future. Fifteen typical wells were taken from the "well belt" which borders the southern shores of San Francisco Bay. As a class they showed high free ammonia (maximum 0.228 parts per million) lower albuminoid ammonia, absence of any fixed relation between the two, and irregular seasonal variation. Nitrites and nitrates were generally absent, but always present in certain particular wells in amounts as large as 0.021 parts per million of nitrites and 1.40 of nitrates. The chlorides varied over as large a range as did those for the streams. The average in the southern part of the district was between fifteen and twenty parts per million, and increased in the northern. The hardness and total solids were about the same as for the streams. The seasonal variation of all the constituents was less marked in the wells than in the streams.

This investigation was undertaken at the suggestion, and was carried out under the inspiration and direction, of Dr. John M. Stillman, Professor of Chemistry at this University.

The writer wishes to acknowledge the courtesy of Captain A. H. Payson, who during his presidency of the Spring Valley Water Co. extended the privilege of sampling the supplies of the company; and of Dr. William Simpson, Health Officer of Santa Clara County, who extended authority to make the necessary local inspections.





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No. 4

Synopsis
of the
True Crabs (Brachyura)
of Monterey Bay
California

BY

FRANK WALTER WEYMOUTH

WITH PLATES I-XIV

(Published November 12, 1910)

STANFORD UNIVERSITY, CALIFORNIA
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TABLE OF CONTENTS.

	PAGE
Introduction	5
Scope and purpose of paper	5
New species	7
Species not previously reported from Monterey Bay	7
List of species treated	8
Key to the suborders of the order Decapoda	11
Key to the tribes of the suborder Reptantia	11
Key to the families of the tribe Brachyura	12
Brachyura of Monterey Bay	14
Subtribe Dromiacea	14
Superfamily Dromiidea	14
Family Dromiidae	14
Subtribe Oxystomata	18
Family Dorippidae	18
Family Leucosiidae	18
Family Calappidae	19
Subtribe Brachygnatha	21
Superfamily Oxyrhyncha	21
Family Parthenopidae	21
Family Inachidae	21
Superfamily Brachyrhyncha	35
Family Cancridae	35
Family Portunidae	49
Family Pilumnidae	50
Family Pinnotheridae	53
Family Grapsidae	61
Bibliography	64
Explanation of plates	65

SYNOPSIS OF THE TRUE CRABS (BRACHYURA) OF MONTEREY BAY, CALIFORNIA

In this paper are included all of the Brachyura or true crabs known from Monterey Bay or from points near enough to make their occurrence there probable, and it is hoped that the keys and figures here given will render easy their identification. It is intended that this shall be one of a series of papers of similar scope dealing with the fauna of Monterey Bay, with a view toward placing at the disposal of workers at the Marine Biological Laboratory an easy means of becoming acquainted with the invertebrates of that region. Preliminary work has been done in several groups, and in the case of the Anomura and the Macrura, the writer hopes to present reports in the near future.

Monterey Bay occupies an open semicircular indentation of the coast line, a little over one hundred miles south of San Francisco, measuring about twenty-five miles from Santa Cruz on the north to Point Pinos on the south, and perhaps ten miles from a line drawn between these two points to the mouth of the Salinas River on the east. The northern and eastern shores of the bay are low and sandy, but from a point near the town of Monterey to Point Pinos and thence south nearly to the town of Carmel, some ten miles, the coast is, with the exception of a few small sandy beaches, extremely rugged, furnishing innumerable rocky tide-pools that form an unusually rich collecting ground, not only for crustacea but for all kinds of invertebrates.

The Stanford Marine Biological Laboratory is located at Pacific Grove, about midway of the southern shore of the bay, and as this has been the central point for shore collecting, the greater part of the work has been confined to four or five miles of the coast, reaching from near Monterey to some distance south of Point Pinos, though a few trips have been made to points north or south of these limits.

Considerable dredging has been done at moderate depths, thirty fathoms and under, from a small launch. Off the eastern shore the bottom is sandy; this has been little worked, but has yielded some valuable specimens. Off the town of Monterey in the southeastern corner of the bay there is a large area of hard blue clay, rich in burrowing mollusks, which has proved a good field for crustacea, and here most of the dredging has been done. Near Point Pinos the bottom is rocky, and would undoubtedly

ly yield much to a more thorough use of the tangle than has yet been attempted.

The present work was begun at the Marine Laboratory during the summer session of 1906, when J. N. Procter and the writer, working under the direction of Dr. G. C. Price, made and indentified a considerable collection of crustacea. It has been finished at Stanford University under the guidance of Dr. H. Heath and Dr. W. K. Fisher, to whom as well as to Dr. G. C. Price, the writer is greatly indebted. The material upon which the work is based has been collected for the greater part by the writer during the three summers of 1906, 1907 and 1908, but includes as well the results of the collecting of numerous students at the Marine Laboratory, among whom the manuscript of the keys has been in use during the session of 1908, and all specimens in the University collection known to have come from Monterey Bay.

The writer wishes to express his obligations to W. F. Allen of Pacific Grove for material, and especially to Miss M. J. Rathbun of the United States National Museum for much kind assistance in determining specimens and for the loan of material.

There has been much excellent work done on the west American crustacea, and the writer is particularly indebted to the papers of S. J. Holmes and Miss M. J. Rathbun. No attempt has been made to duplicate the full descriptions of Holmes, attention being confined to the noting of variations or other points of interest except in the case of a few species, whose descriptions are incomplete or not easily accessible, and which have been treated at some length.

The writer has followed Borradaile (*Annals and Magazine of Natural History*, Seventh series, vol. 19, p. 457) in the use of the suborders Natantia and Reptantia instead of Macrura and Brachyura (or Macrura, Anomura and Brachyura) and in the inclusion of the Dromiidae with the Brachyura instead of with the Anomura. The keys to suborders and tribes are taken from his paper with some modifications. In the arrangement of families, though not of species, Miss Rathbun (*Decapod Crustaceans of the Northwest Coast of North America, Harriman Alaska Expedition*, vol. 10) has been followed.

Fifty-two species are here treated. Of these, the occurrence of forty-three is well established, six rest on doubtful records and three more are included because found in adjacent regions or for completeness. Of the forty-three species thirty-six are represented in the collection at hand. One new species is here described. The following lists set forth these facts more clearly.

New species:

Dromidia segnipes.

Species not previously reported from Monterey Bay:

Randallia bulligera

Podocheila hemphillii

Dasygyus tuberculatus

Rhodia parvifrons

Cycloxanthops novemdentatus

Lophopanopeus diegensis

? *Pinnixa occidentalis*

LIST OF SPECIES TREATED IN THE PRESENT PAPER

Order Decapoda.

Suborder Reptantia.

Tribe Brachyura.

Subtribe Dromiacea.

Superfamily Dromiidea.

Family Dromiidae.

1. Genus *Dromidia* COLLECTED REPORTED1. *D. segnipes* n. sp.x.....

Subtribe Oxystomata.

Family Dorippidae.

2. Genus *Clythrocerus*.2. *C. planus* (Rathbun)..... ?

Family Leucosiidae.

3. Genus *Randallia*.3. *R. ornata* (Randall).....x..... x4. *R. bulligera* Rathbun.....x.....

Family Calappidae.

4. Genus *Mursia*.5. *M. gaudichaudii* (Milne Edwards) x..... x

Subtribe Brachygnatha.

Superfamily Oxyrhyncha.

Family Parthenopidae.

5. Genus *Heterocrypta*.6. *H. occidentalis* (Dana).....x..... x

Family Inachidae.

6. Genus *Podochela*.7. *P. hemphillii* (Lockington).....x.....7. Genus *Erileptus*.8. *E. spinosus* Rathbun..... ?8. Genus *Anasimus*.9. *A. rostratus* Rathbun..... ?9. Genus *Dasygyius*.10. *D. tuberculatus* (Lockington)....x.....10. Genus *Epialtus*.11. *E. bituberculatus* Milne Edwards. ?12. *E. productus* Randall.....x..... x

11. Genus *Pugettia*.
 13. *P. gracilis* Dana..... x
 14. *P. richii* Dana.....x..... x
12. Genus *Mimulus*.
 15. *M. foliatus* Stimpson.....x.....x
13. Genus *Loxorhynchus*.
 16. *L. grandis* Stimpson.....x.....x
 17. *L. crispatus* Stimpson.....x.....x
14. Genus *Chorilia*.
 18. *C. longipes* Dana..... x
15. Genus *Scyra*.
 19. *S. acutifrons* Dana.....x.....x
16. Genus *Rhodia*.
 20. *R. parvifrons* (Randall).....x.....
17. Genus *Chionoecetes*.
 21. *C. tanneri* Rathbun.....x.....x
- Superfamily Brachyrrhyncha.
 - Family Cancridæ.
 18. Genus *Cancer*.
 22. *C. productus* Randallx.....x
 23. *C. magister* Dana.....x.....x
 24. *C. gracilis* Dana.....x.....x
 25. *C. gibbosulus* (de Haan).....x.....x
 26. *C. jordani* Rathbun.....x.....x
 27. (*C. amphioetus* Rathbun).....
 28. *C. antennarius* Stimpson.....x.....x
 29. (*C. anthonyi* Rathbun).....
 30. *C. oregonensis* (Dana)..... x
 - Family Portunidæ.
 19. Genus *Portunus*.
 31. (*P. xantusii* (Stimpson))..... ?
 - Family Pilumnidæ.
 20. Genus *Cycloxanthops*.
 32. *C. novemdentatus* (Lock.).....x.....
 21. Genus *Lophopanopeus*.
 33. *L. bellus* (Stimpson).....x.....x
 34. *L. heathii* Rathbun.....x.....x
 35. *L. leucomanus* (Lock.)..... x
 36. *L. diegensis* Rathbun.....x.....
 22. Genus *Xanthias*.
 37. *X. taylori* (Stimpson).....x.....x

Family Pinnotheridæ.

23. Genus *Pinnotheres*.
 38. *P. nudus* Holmes.....x.....x
 24. Genus *Raphonotus*.
 39. *R. subquadratus* (Dana).....x.....x
 25. Genus *Pinnixa*.
 40. *P. occidentalis* Rathbun..... ?
 41. *P. californiensis* Rathbun.....x.....x
 42. *P. tubicola* Holmes.....x.....x
 43. *P. littoralis* Holmes.....x.....x
 44. *P. longipes* (Lock.).....x.....x
 45. *P. faba* (Dana).....x.....x
 26. Genus *Scleroplax*.
 46. *S. granulata* Rathbun.....x
 27. Genus *Cryptophrys*.
 47. *C. concharum* Rathbun.....x
 28. Genus *Opisthopus*.
 48. *O. transversus* Rathbun.....x.....x

Family Grapsidæ.

29. Genus *Pachygrapsus*.
 49. *P. crassipes* Randall.....x.....x
 30. Genus *Hemigrapsus*.
 50. *H. nudus* (Dana).....x.....x
 51. *H. oregonsis* (Dana).....x.....x
 31. Genus *Planus*.
 52. (*P. minutus* (Linnæus))..... ?

KEY TO THE SUBORDERS OF THE ORDER DECAPODA.

- a.* Rostrum seldom reduced or absent, if well developed almost invariably compressed. Body always compressed. First abdominal segment not much smaller than the rest. First antenna generally bears a scale at base; second antennal scale generally large. Legs slender (except sometimes a stout chelate limb or pair of limbs which may be any one of first three) with basipodite and ischiopodite never fused, only one fixed point in the carpo-propodal articulation. Abdominal limbs 1-5 always present in full number, well developed, and used for swimming. *Natantia*
- aa.* Rostrum often reduced or absent, depressed if present. Body not compressed, generally depressed. First abdominal segment distinctly smaller than the rest. No scale on first antenna; that on second antenna never large, generally small or absent. Legs stout, the first usually, the others never, stouter than their fellows; basipodite and ischiopodite almost always fused in the first pair, generally in others, two fixed points in the carpo-propodal articulation. Abdominal limbs 1-5 often reduced or absent, not used for swimming. *Reptantia*

KEY TO THE TRIBES OF THE SUBORDER REPTANTIA.

- a.* Carapace not fused with epistome; last thoracic sternum free, its legs reduced, often chelate, always differing from the third pair. Abdomen large and extended or reduced and loosely folded under carapace, generally (except in *Lithodidæ*) with biramous appendages on the sixth segment. Antennæ (second) well developed, situated external to eye, with long flagella and often a movable scale. *Anomura*
- aa.* Carapace fused with epistome at sides and nearly always also in middle; last thoracic sternum fused with others, its legs never chelate, seldom markedly different from the others. Abdomen much reduced, symmetrical, closely folded beneath thorax, never with biramous appendages on sixth segment (only in *Dromidæ* is the sixth pair present even in a rudimentary condition). Antennæ (second) situated internal to eye, seldom with long flagella, never with movable scale. *Brachyura*

KEY TO THE FAMILIES OF THE TRIBE BRACHYURA.

- a.* Second antennæ long (flagellum equal to more than half the width of the carapace); first antennæ without special fossettes, first abdominal legs of female present, uropods rudimentary or absent, female openings in coxæ of legs, gills numerous.

Subtribe *DROMIACEA*, Fam. *Dromiidae*

- aa.* Second antennæ short (never equal to half the width of the carapace) first antennæ usually lodged in special fossettes, first abdominal legs of female wanting, uropods never present, female openings in sternum (rarely in coxæ), gills few.

- b.* Buccal frame triangular, narrowed forward; efferent branchial channels opening at middle of endostome.

Subtribe *OXYSTOMATA*

- c.* Last 1 or 2 pairs of legs reduced in size and articulated higher than preceding pairs, so as to lie on dorsal surface of body.

Fam. *Dorippidae*

- cc.* Legs normal in size and position.

- d.* Maxillipeds closing the buccal cavern; the palp hidden by the triangular merus.

Fam. *Leucosiidae*

- dd.* Maxillipeds not completely closing the buccal cavern; the palp always exposed.

Fam. *Calappidae*

- bb.* Buccal frame quadrate; efferent branchial channels opening at sides of endostome.

Subtribe *BRACHYGNATHA*

- c.* Carapace usually triangular, with pointed or spined rostrum; the branchial region inflated, the hepatic region small; orbits usually incomplete.

Superfam. *Oxyrhyncha*

- d.* Basal antennal joint very small and short, not reaching farther forward than posterior margin of orbit; hard basal joint of antennule reaching orbit and forming part of inferior margin. Chelipeds much longer and more massive than other legs.

Fam. *Parthenopidae*

- dd.* Basal antennal joint well developed, reaching at least to anterior margin of orbit, of the lower margin of which it forms the greater part; basal antennular joint usually soft and concealed in fossette, never reaching orbit. Chelipeds not markedly longer or more massive than other legs.

Fam. *Inachidae*

cc. Carapace without rostrum, usually broad, never with the hepatic region greatly reduced; orbits generally well enclosed. Superfam. *Brachyrhyncha*

d. Carapace generally broader than long, wide and regularly arcuated in front; lateral margins markedly convergent behind. Frontal region not markedly broad, generally produced horizontally in lobes or teeth.

e. Antennules folded longitudinally, front with several teeth one of which is median; outer maxillipeds overlapping the endostome.

Fam. *Cancridae*

ee. Antennules folded transversely or obliquely transversely, front with or without median tooth; outer maxillipeds not overlapping endostome.

f. Last pair of legs usually modified for swimming, with the last two joints very broad and paddle-like. Anterolateral border sharply marked off from postero-lateral. Front with or without median tooth. Fam. *Portunidae*

ff. Last pair of legs not modified for swimming. Antero-lateral border of carapace not sharply marked off from postero-lateral. Front generally divided by a median notch.

Fam. *Pilumnidae*

dd. Carapace usually quadrilateral; lateral margins nearly parallel. Frontal region usually broad, bent downwards and without teeth or sharp lobes.

e. Carapace often more or less membranaceous; front, orbits and eye-stalks usually very small; buccal frame arcuate in front. Species small, generally commensal. Fam. *Pinnotheridae*

ee. Carapace hard and firm; front, orbits and eye-stalks not markedly small; buccal frame quadrate in front.

f. Front usually markedly broad; eye-stalks of moderate size. Fam. *Grapsidae*

ff. Front of moderate width or very narrow; eye-stalks often greatly elongated.

Fam. *Ocypodidae*

Tribe BRACHYURA.

Subtribe DROMIACEA.

Superfamily DROMIIDÆ.

Family DROMIIDÆ.

No representative of this family has been recorded, as far as I am aware, from the west coast of North America north of the Mexican boundary. *Hypochoncha panamensis* is recorded by Faxon* from the west coast of Panama, but beyond this I do not know that any of the Dromiidæ have been reported from Mexico or Central America. It is therefore no inconsiderable addition to our western crustacean fauna to record a new Dromid from Monterey Bay. Two specimens were obtained in the summer of 1906 while dredging in shallow water, and although special effort was made during the two following summers to obtain more material these remain the only examples. The species proves to be a very close relative of *Dromidia antillensis* Stimpson, and further knowledge of its distribution may show it to be one of the numerous pairs of species found on opposite sides of the isthmus.

Genus DROMIDIA Stimpson.

Dromidia Stimpson, Proc. Acad. Nat. Sci. Phila., p. 63, 1858 (Type—*Dromidia hirsutissima* (Lamark)).

Stimpson in defining this genus says,† “In the sternum of the female the copulatory sulci are produced, and approximated at their extremities in a more or less tuberculiform projection situated between the bases of the chelipeds.” According to Miss Rathbun this description should be modified, as the sulci do not always end in a single tubercle. In the specimen here described the sulci end in distinct tubercles, and it is interesting to observe that in the most closely related form, *D. antillensis*, the single

* Faxon, Memoirs Harvard Mus. Comp. Zool., xviii, 237.

† Stimpson, Proc. Acad. Nat. Sci. Phila., 1858, 225.—Report on the Crustacea collected by the North Pacific Exploring Expedition, Smithsonian Miscellaneous Collections, No. 1717, 170.

tubercle there present shows, according to Henderson,* "a slight trace of bifurcation in front."

***Dromidia segnipes* sp. nov.**

Plate I, figs. 1-2.

Carapace pubescent, markedly convex, and about as long as wide. Stimpson describes *Dromidia antillensis*, the most closely related form, as "somewhat longer than broad" and gives the following measurements: "length of carapax, 1.30; breadth, 1.28 inch." The specimen at hand is considerably smaller and is broader than long, measuring 15 by 15.7 mm., but these relative proportions may be found to vary with age, as Henderson * gives the measurements of an immature *D. antillensis* 13.5 long by 13.8 mm. wide. Front tridentate, the inner angles of the orbits more prominent than the rostral point, so that the front seems divided by a deep rounded notch when seen from above. In *D. antillensis* these teeth are stated to be subequal. Supraorbital teeth considerably smaller and more acute than those of front. External angle of orbit prominent and bounded by a marked fissure, as in *D. antillensis*.

The antero-lateral margin of the carapace is four-toothed as in *D. antillensis* but the teeth are obscured to superficial examination by the pubescence. The most posterior, located just behind the cervical groove, is acute and directed forward; the next anterior to this is the most prominent and forms the greatest width of the carapace, it is also acute; the next is smaller but still acute; these alone are visible from above. The most anterior is very low and rounded, resembling more the tubercle at the angle of the buccal cavern than the preceding teeth. In *D. antillensis* the three anterior teeth are said by Stimpson to be "subspiniiform," and by Benedict † to be "little more than enlarged granules." The tooth posterior to the cervical groove is also stated to be less acute than the others, which is not the case in the specimen at hand.

The pubescence of the carapace is somewhat longer and more dense in the frontal region and sparser in the branchial regions. On removing the pubescence the carapace is seen to be glabrous and definitely, though not deeply areolated. The cervical groove, the most prominent of the markings, runs from a point just anterior to the last antero-lateral tooth nearly to the middle of the posterior margin of the carapace, where it be-

* Henderson, Challenger Anomura, Part lxix, 12.

† Benedict, U. S. Fish Commission Bull. for 1900, ii, 132.

comes indistinct. The lateral margins of the cardiac region anterior to the cervical groove are marked by distinct sulci, external to which are low elevations, the anterior border is marked by a much less definite sulcus concave in front. In the type (male) which was carrying what was apparently a sand-encrusted ascidian, nearly all of the carapace lateral and posterior to the cervical groove, with the exception of the intestinal region, is membranaceous; while in the second specimen, a female, only the sub-branchial region is uncalcified.

Antennæ prominent, the basal portion four-jointed, the basal joint wider than long, the green gland opening at its inner margin between two acute inwardly projecting tubercles, the second joint the longest, projecting far enough to be slightly visible from above, the last two joints small, subequal, inserted in a deep rounded notch in the antero-internal angle of the preceding joint, the flagellum sparingly ciliated, more than half the length of the carapace. Lower orbital margin ending in a prominent obtuse tooth next the basal portion of the antennæ. Basal joint of the antennule large, reaching about to insertion of last two joints of the antenna, last two joints subequal; the last with two unequal brushes of hairs at the tip; in the normal position the last two joints are almost entirely concealed.

Endostome with a low ridge on either side bounding the efferent branchial channels. External maxillipeds stout, the ischium slightly wider at the distal end and armed on the inner margin with a row of 7 or 8 conical, corneous-tipped spines, the merus rectangular, slightly shorter than the ischium, distally truncated, very slightly rounded, both corners square. Palp articulated to inner side of merus near tip, entirely visible when in normal position; exognath nearly reaching tip of merus, tapering but little.

Chelipeds hairy except tips of fingers, stout, ischium small without prominent armature, merus trigonal, all the angles denticulated, a wide transverse sulcus above paralleling the distal margin, carpus short and stout, denticulated at anterior angles, hand without any conspicuous spines or tubercles. In these characters it does not differ widely from Stimpson's description of *D. antillensis*. The tips of the fingers are calcareous, of a light flesh color, markedly excavated at the tip and armed with large triangular teeth which interlock at the tip but gape pronouncedly at the base.

Ambulatory legs hairy, less stout than chelipeds but hardly "slender" as in *D. antillensis*. The last pair are unfortunately missing in both specimens; of those remaining the first and second are the largest and differ little in size, they are unarmed with the exception of the dactyls which terminate in strong, curved, corneous spines and are further armed with three or four straight corneous spines on the lower margin. The third

ambulatory leg is much smaller, reaching scarcely to the tip of the carpus of the preceding pair, the dactyl is more sharply curved and lacks the secondary spines, the inferior distal angle of the propodus is provided with a nearly straight spine which may be opposed to the dactyl, thus making the appendage subcheliform. The last pair were apparently entirely dorsal in position.

Abdomen of male seven-jointed, much constricted between the first and second segments and widest at distal end of second, from which it tapers evenly to the seventh, which is obtusely triangular. First segment the shortest, second, third, fourth, and fifth subequal, sixth and seventh increasingly longer. The penultimate joint is said to be long and slender in *D. antillensis*. The rudimentary uropods are present in a slight notch between the sixth and seventh segments, barely visible from the outside.

Abdomen of the female seven-jointed, much constricted between the first and second segments, and widest at the third, from which it tapers gradually to the seventh, which is evenly rounded. The median portion is raised, forming a rounded ridge, the whole evenly pubescent. The uropods are present as in the male. The sternal sulci extend from the base of the third pair of legs to the center of the sternum of the chelipeds, where they end in closely approximated but distinct low tubercles. Abdominal appendages present on all the segments.

Color in alcohol, yellowish tan, tips of chelipeds flesh color; color in life similar.

MEASUREMENTS	MALE (TYPE)	FEMALE
Length of carapace	15.0 mm.	15.7 mm.
Width of carapace	15.7	16.3
Length of antennal flagellum	11.0	10.0

Type No. 478, cotype No. 479, Invertebrate Series, Leland Stanford Junior University Zoological Museum.

Subtribe OXYSTOMATA.

Family DORIPPIDÆ.

Genus **CLYTHROCERUS** A. Milne Edwards & Bouvier.

Clythrocerus A. Milne Edwards & Bouvier, Bull. Mus. Hist. Nat. Paris, v, 387, 1899
(Type—*Clythrocerus nitida* A. Milne Edwards).

Clythrocerus planus (Rathbun).

Cyclodorippe plana Rathbun, Amer. Nat., xxxiv, 519, 1900.

Clythrocerus planus Rathbun, H. A. E., x, 168, 1904.

"Catalina and possibly Monterey. . . under 50 fathoms" (Rathbun).
In the American Naturalist the footnote giving the type locality is erroneously attached to *C. nitida* A. Milne Edwards, an Atlantic form. I have seen no specimen of this species.

Family LEUCOSIIDÆ.

Genus **RANDALLIA** Stimpson.

Randallia Stimpson, Proc. Bost. Soc. Nat. Hist., vi, 85, 1857; Journ. Bost. Soc. Nat. Hist., vi, 471, 1857 (Type—*Randallia ornata* (Stimpson)).

Key to species.

- a. Carapace of adult nearly smooth, young with unequal smooth tubercles,
size large. *R. ornata*
- aa. Carapace of adult covered with nearly equal minutely spinous tubercles,
size small. *R. bulligera*

Randallia ornata (Randall).

Plate I, fig. 3.

Ilia ornata Randall, Journ. Acad. Nat. Sci. Phila., viii, 129, 1839.

Randallia ornata Holmes, Occas. Papers Calif. Acad. Sci., vii, 100, 1900, and
synonymy.—Rathbun, H. A. E., x, 170, 1904.

Represented in the collection by a few adults brought in by Chinese fisherman, and several immature specimens about 10 mm. long.

Randallia bulligera Rathbun.

Randallia bulligera Rathbun, Proc. U. S. Nat. Mus., xxi, 614, pl. xlv, fig. 6, 1898.

—Holmes, Occas. Papers Calif. Acad. Sci., vii, 101, 1900.—Rathbun, H. A. E., x, 170, 1904.

I have placed in this species two small specimens dredged from ten fathoms, measuring 8x9 mm. and 6.2x7.2 mm. respectively, which, though they do not tally in all points with the descriptions given by Holmes and Rathbun, agree in certain features and seem to be fairly distinct from specimens of *R. ornata* of the same size. The most marked difference is in the tubercles, which in these specimens are set close together and are fairly uniform in size, though with a few smaller ones interspersed, and present when dried and examined by a lens a thick coat of minute spines. When wet these spines are not noticeable and tend to give the tubercle a "pearly" appearance, so that they might easily be called "smooth" as in Holmes's description. In the young of *ornata* the tubercles are more scattered and of unequal sizes and show no spines. The pollex of the cheliped in *ornata* is about equal to the length of the palm, while in these specimens it is shorter. I can see no other prominent differences and as the specimens fail to show the prominent trilobing of the margin of the efferent branchial channels and the relative position of the posterior prominences mentioned by Rathbun and Holmes, I have felt some hesitation in calling them *bulligera*.

Randallia bulligera has been reported from Magdalena Bay and from off San Diego, but not previously from Monterey Bay.

Family CALAPPIDÆ.**Genus MURSIA** Desmarest.

Mursia Desmarest, Consid. sur les Crust., 108, footnote, 1825.—Milne Edwards, Hist. Nat. Crust., ii, 109, 1837.

Thealia Lucas, Ann. Soc. entom. France, ser. 1, viii, 577, 1839 (Type—*Mursia cristamana* de Haan).

Mursia gaudichaudii (Milne Edwards).

Platymera gaudichaudii Milne Edwards, Hist. Nat. Crust., t. ii, 180, 1837.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 99, 1900, and synonymy.—Rathbun, H. A. E., x, 170, 1904.

I have had the opportunity of examining two specimens, both males, in the possession of W. F. Allen, who said that they were obtained in considerable numbers by fishermen seining in moderately deep water on a muddy bottom off the mouth of the Salinas River. These agree well with Holmes's description, but possess a pair of very prominent tubercles on the sternum of the segment bearing the chelipeds, not mentioned by him.

I have followed Miss Rathbun* in uniting *Platymera* with *Mursia*.

* U. S. Fish Commission Bulletin for 1903, 888.

Subtribe BRACHYGNATHA.

Superfamily OXYRHYNCHA.

Family PARTHENOPIDÆ.

Genus **HETEROCRYPTA** Stimpson.

Heterocrypta Stimpson, Ann. Lyc. Nat. Hist. N. Y., x, 102, 1871 (Type—*Heterocrypta granulata* (Gibbes)).

***Heterocrypta occidentalis* (Dana).**

Plate II, figs. 4-5.

Cryptopodia occidentalis Dana, Am. Journ. Sci. (2), xviii, 430, 1854.—Rathbun, Am. Nat., xxxiv, 516, 1900.

Heterocrypta occidentalis Holmes, Occas. Papers Calif. Acad. Sci., vii, 44, 1900, and synonymy.—Rathbun, H. A. E., x, 170, 1904.

Represented in the collection by a considerable number of specimens, all dredged from moderate depths—ten to fifteen fathoms.

The rostrum in the younger specimens is rather more acute than in the adult and there is also considerable pubescence along the angles of the chelipeds and especially in the branchial and frontal regions, sometimes covering the greater part of the carapace, while the carapace of the adult is commonly smooth. As shown in the figures, the middle of the posterior margin of the carapace is more prominently rounded in the female than in the male.

Color in life: tips of tubercles white, ridges bearing tubercles light purplish, remainder of carapace mottled with numerous minute spots of white and purplish, giving a pink effect which often closely approaches white. Ambulatory legs usually a light yellow. Color in alcohol not markedly different.

Family INACHIDÆ.

Specimens of all the species of Inachidæ here treated, 11 in number, have been available for examination, and considerable pains has been

taken in the construction of keys, as this family usually proves troublesome to the novice, chiefly, it would seem, because of the characters made use of in keys, which are commonly, and almost necessarily, inaccessible or indefinite. The degree of completeness of the orbit, though undoubtedly one of the most obvious of certain modifications involving the greater part of the head region, is generally used in a comparative manner as "more" or "less complete," which except to the person familiar with the forms is little better than useless. When present the orbit seems to be formed by the development of the pre- and post-ocular spines and by the expansion of the basal antennal joint. Of these the post-ocular spine is the most important; absent or distant from the eye in forms like *Podochela* and *Erileptus*, it becomes, in *Chionoecetes* and allied species, cup-shaped, and into this cavity the eye is retracted. I have attempted to make use of this character in the generic key, which follows in part that of Miss Rathbun on this group.* A second key based on more obvious and accessible characters and including the species is given as an additional aid.

Some interesting correlations were noted in the series, which though probably not unknown, I have not seen pointed out before. The length of the rostrum is correlated, not only, as might be expected, with the length of the carapace, but also with the length of the antennæ. The flagellum is usually somewhat shorter than the rostrum and corresponds quite closely to it in length; this is especially noticeable in comparing a form with a long slender rostrum as *Chorilia* with one having a short rostrum, as *Chionoecetes*. In a few cases (*Mimulus*) the antennæ exceed the rostrum. As follows from the length, the antennæ correspond in stoutness with the rostrum; but in addition, those species having markedly flattened rostrums are found to have flattened antennæ (*Scyra*, *Pugettia*) while those with long cylindrical horns forming the rostrum have cylindrical antennæ (*Chorilia*).

I have followed Miss Rathbun in ignoring, as in the report on the Decapods of the Harriman Expedition, the subfamilies of this group, which seem, at least on this coast, to be of little service and incapable of sharp distinction.

* Am. Nat., xxxiv, 503-520, 1900.

KEY TO GENERA OF INACHIDÆ FOUND IN MONTEREY BAY.

- a. Length of basal antennal joint (measured from raised margin of endostome to insertion of free joints) greater than, or equal to, the combined width of the same joints and that portion of the epistome or antennular fossettes lying between them, measured from bases of eye-stalks (middle of lower orbital margin).
 - b. Post-ocular spine inconspicuous and distant from eye.
 - c. Chelipeds fairly short and stout (dactyl about equal to palm), no supraocular spine. *Podocheila*
 - cc. Chelipeds long and slender (dactyl equal to about one-third palm), a prominent supra-ocular spine. *Erileptus*
 - bb. Post-ocular spine prominent and close to eye.
 - c. A prominent, acute supra-ocular spine. *Anasimus*
 - cc. Upper margin of orbit prominent, but without a spine. *Dasygygius*
- aa. Length of basal antennal joint less than distance between lower orbital margins (usually in the proportion of 2 to 3).
 - b. Post-ocular spine, if present, with anterior face convex or flattened so that cornea of retracted eye is always visible from above; exognath of outer maxilliped widest in distal half, tapering abruptly.
 - c. Lateral margins of carapace not markedly flattened or produced.
 - d. Surface of carapace smooth or undulated. *Epialtus*
 - dd. Surface of carapace with spines or tubercles. *Pugettia*
 - cc. Lateral margins of carapace markedly flattened and produced. *Mimulus*
 - bb. Post-ocular spine cupped or with dense growth of hair on anterior face so that cornea of retracted eye is partially concealed from above; exognath of outer maxilliped widest in basal half, tapering gradually.
 - c. Post-ocular spine flattened and densely hairy on anterior face. *Loxorhynchus*
 - cc. Post-ocular spine deeply cupped on anterior face and without hairs.
 - d. A supra-ocular spine present.

- e.* Rostrum composed of two long, slender, cylindrical horns. *Chorilia*
- ee.* Rostrum composed of two short, flattened horns.
 - f.* Outer margin of basal antennal joint flattened and produced, not spiny. *Scyra*
 - ff.* Outer margin of basal antennal joint not produced, spiny. *Rhodia*
- dd.* No supra-ocular spine. *Chionoecetes*

KEY TO SPECIES OF INACHIDÆ FOUND IN MONTEREY BAY.

- a.* Rostrum simple.
 - b.* Rostrum slender; ambulatory legs slender, long (equal to at least twice the width of carapace).
 - c.* Chelipeds long, slender; dactyl about one-fourth total length of hand. *Erileptus spinosus*
 - cc.* Chelipeds moderately short and stout; dactyl about one-half total length of hand.
 - d.* Carapace much elongated in front, depressed, not spiny, rostrum long. *Podochela hemphillii*
 - dd.* Carapace not elongated in front, not depressed, rostrum short.
 - e.* Acute supra-ocular spine, low tubercle on first abdominal joint. *Anasimus rostratus*
 - ee.* No acute supra-ocular spine, prominent spine on first abdominal joint. *Dasygyius tuberculatus*
 - bb.* Rostrum stout, blunt; ambulatory legs short (less than twice the width of carapace). No spines on carapace. *Epialtus bituberculatus*
- aa.* Rostrum bifid.
 - b.* Rostral horns short or moderate (never exceeding one-fourth the total length of carapace), stout, more or less flattened.
 - c.* Surface of carapace more or less undulated, smooth.
 - d.* Margin of carapace not markedly thin and produced. *Epialtus productus*
 - dd.* Entire margin of carapace thin and produced in a leaf-like expansion. *Mimulus foliatus*

- cc. Surface of carapace markedly tubercular or spiny.
 - d. Carapace sub-pyriform or lyrate, rostrum moderate or long (one-fourth to one-sixth total length of carapace).
 - e. Rostral horns extremely flattened and leaf-like, not markedly divergent in adult. *Scyra acutifrons*
 - ee. Rostral horns never greatly flattened, more or less divergent.
 - f. Carapace undulated, with few moderate tubercles.
 - g. Post-ocular spine and first antero-lateral tooth united by a leaf-like expansion of the carapace. *Pugettia gracilis*
 - gg. Post-ocular spine and first antero-lateral tooth acute and distinct. *Pugettia richii*
 - ff. Carapace with numerous or very prominent tubercles.
 - g. Tubercles small and numerous, carapace markedly convex. *Loxorhynchus grandis*
 - gg. Tubercles comparatively few, large and prominent, carapace not convex. *Loxorhynchus crispatus*
 - dd. Carapace sub-orbicular, rostrum very short (one-ninth or one-tenth of total length of carapace).
 - e. Ambulatory legs long (equal to twice the width of carapace), no supra-ocular spine. *Chionoecetes tanneri*
 - ee. Ambulatory legs moderate (about equal to once and a half the width of carapace), an acute supra-ocular spine. *Rhodia parvifrons*
 - bb. Rostral horns long (about one-third the total length of carapace), slender, cylindrical. *Chorilia longipes*

Genus PODOCHELA Stimpson.

Podochela Stimpson, Ann. Lyc. Nat. Hist. N. Y., vii, 194, 1860.

Coryrhynchus Kingsley, Pro. Acad. Nat. Sci. Phila., 384, 1879 (Type—*Podochela grossipes* Stimpson).

***Podochela hemphillii* (Lockington).**

Plate II, fig. 6.

Microrhynchus hemphillii Lockington, Proc. Calif. Acad. Sci., vii, 30, 1877.

Podochela hemphillii Holmes, Occas. Papers Calif. Acad. Sci., vii, 17, 1900, and synonymy.—Rathbun, H. A. E., 171, 1904.

A single specimen of this genus was dredged in the summer of 1906, and though special effort was made to obtain more, none were found during either of the following summers. The specimen at hand differs in no essential respect from Holmes's rather full description of *P. hemphillii* except in the length of the rostrum. This feature is not very definitely stated by Holmes, who says that the rostrum "varies considerably in length, being sometimes broadly and sometimes narrowly triangular." In the figure given by Miss Rathbun the length of the rostrum (measured from the tip to the supra-ocular spine) is about one-fourth of the total length of the carapace, while in the Monterey specimen the rostrum equals about two-fifths of the total length. Miss Rathbun, who has examined the specimen, thought that it might prove a new species, but I hesitate to separate it on the single character of the length of the rostrum without a considerable series for comparison, especially since a specimen from Catalina Island (the only other *Podochela* at hand) shows a rostrum in some degree intermediate. Further material may prove it distinct, but for the present it seems best to list it as *P. hemphillii*, a record which materially increases its range, which as given by Miss Rathbun is "from San Luis Obispo, Cal., to Gulf of California."

Genus ERILEPTUS Rathbun.

Erileptus Rathbun, Proc. U. S. Nat. Mus., vol. xvi, 227, 1893 (Type—*Erileptus spinosus* Rathbun).

Erileptus spinosus Rathbun.

Plate III, fig. 7.

Erileptus spinosus Rathbun, Proc. U. S. Nat. Mus., xvi, 277, 1893.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 21, 1900.—Rathbun, H. A. E., x, 171, pl. x, fig. 1, 1904.

This and the following species are included on the range given by Miss Rathbun from specimens collected by W. H. Dall in "southern California (either at Catalina Harbor or Monterey)." I have examined a specimen kindly loaned by Miss Rathbun and one obtained at Catalina by S. S. Berry. Though I have seen no specimens from Monterey, it is not at all improbable that it may occur there, in view of the number of spider crabs previously recorded only from the south (*Podochela*, *Rhodia parvifrons*, *Dasygyius tuberculatus*) which have been obtained during a comparatively small amount of collecting.

Genus ANASIMUS A. Milne Edwards.

Anasimus A. Milne Edwards, Crust. Reg. Mex., 350, 1880 (Type—*Anasimus fugax* A. Milne Edwards).

Anasimus rostratus Rathbun.

Anasimus rostratus Rathbun, Proc. U. S. Nat. Mus., xvi, 277, 1893.—Rathbun, H. A. E., x, 171, pl. x, fig. 4, 1904.

As before stated, this species is included on Miss Rathbun's authority. I have examined a specimen from the southern part of the state which she kindly loaned.

Genus DASYGYIUS Rathbun.

Microhynchus Bell, Proc. Zool. Soc. London, 88, 1835 (Preoccupied).
Neorhynchus A. Milne Edwards, Crust. Reg. Mex., 350, 1880 (Preoccupied).
Dasygyius Rathbun, Proc. Bio. Soc. Wash., xi, 164, 1897 (Type—*Dasygyius gibbosus* (Bell)).

Dasygyius tuberculatus (Lockington).

Plate III, fig. 8.

Inachus tuberculatus Lockington, Proc. Calif. Acad. Sci., vii, 30, 1877.
Dasygyius tuberculatus Holmes, Occas. Papers Calif. Acad. Sci., vii, 27, 1900, and synonymy.—Rathbun, H. A. E., 172, pl. x, fig. 3, 3a, 1904.

A single male specimen was dredged from 45 fathoms. As this species was previously reported from San Diego and Alamitos Bay, this is a material increase of range.

Genus **EPIALTUS** Milne Edwards.

Epialtus Milne Edwards, Hist. Nat. Crust., i, 344, 1834 (Type—*Epialtus bituberculatus* Milne Edwards).

Key to species.

- | | |
|------------------------------------------|--------------------------|
| a. Rostrum entire, no post-ocular spine. | <i>E. bituberculatus</i> |
| aa. Rostrum bifid, a post-ocular spine. | <i>E. productus</i> |

Epialtus bituberculatus Milne Edwards.

Epialtus bituberculatus Milne Edwards, Hist. Nat. Crust., i, 345, pl. 15, fig. 11, 1834.
—Rathbun, H. A. E., x, 173, 1904, and synonymy.

"Southern California (either Catalina Harbor or Monterey)" Rathbun. Its occurrence seems very doubtful; if found it should be easily distinguished by its small size, as compared with *E. productus*, and its entire rostrum.

Epialtus productus Randall.

Plate III, fig. 9.

Epialtus productus Randall, Journ. Acad. Nat. Sci. Phila., viii, 110, 1839.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 22, 1900, and synonymy.—Rathbun, H. A. E., x, 173, 1904.

This species, next to *Cancer antennarius* and *Cancer productus* which probably exceed it in weight, is the largest of the common shore crabs of Monterey Bay and is one of the few on the coast which aspire to the dignity of a common name, being called the "kelp crab" because, according to Holmes it is usually found on kelp which it closely resembles in color. The young are common along shore chiefly among the seaweed, but most of the adults obtained have come from the piles of the Monterey wharves, though it is found on floating kelp and on buoys. It is often affected with a sacculina, and seems to be the only species commonly so parasitized, as I have examined many specimens of other species and have never found a sacculina.

Color in life varies from dark brown to tan, the lighter shades being found in young and apparently in recently moulted individuals in which also the dark spots mentioned by Holmes are inconspicuous or absent. Underparts reddish, often a bright brick red, sometimes with light markings on the coxæ of the ambulatory legs and on the external maxillipeds.

The following are the measurements of a large male and female.

	MALE	FEMALE
Length, tip of rostrum to back of carapace.....	170 mm.	92 mm.
Width of carapace at first antero-lateral tooth....	84	78
Width of " " second " " " " " "	93	82
Length of chelipeds	195	90
Length of first ambulatory leg.....	163	118

(*Epialtus nuttallii* Randall — distinguished from *E. productus* by much less prominent lateral teeth and the absence of the postocular tooth — occurs at San Diego and Santa Barbara and may be found to extend as far north as Monterey.)

Genus **PUGETTIA** Dana.

Pugettia Dana, Amer. Journ. Sci. and Arts, ser. 2, vol. xi, 268, 1851; U. S. Explor. Expd., Crust., xiii, 84, 1852 (Type—*Pugettia gracilis* Dana).

Key to species.

- a. Post-ocular spine and first antero-lateral tooth united by a leaf-like expansion of the carapace. *P. gracilis*
- aa. Post-ocular spine and first antero-lateral tooth acute and distinct. *P. richii*

Pugettia gracilis Dana.

Plate IV, fig. 10.

Pugettia gracilis Dana, Am. Journ. Sci. (2), xi, 268, 1851.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 25, 1900, and synonymy.—Rathbun, H. A. E., x, 173, 1904.

Aleutian Is. to southern California; Rathbun, Holmes. It seems rather surprising that among the large series of *Pugettia* examined this species should not appear though reported from both north and south of the Bay. I have examined specimens from Alaska.

Pugettia richii Dana.

Plate IV, fig. 11.

Pugettia richii Dana, Am. Journ. Sci. (2), xi, 268, 1851.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 24, 1900, and synonymy.—Rathbun, H. A. E., x, 173, 1904.

A series of about 50, though showing considerable variation, corresponds well with Holmes's description. The females differ from the males in possessing a more tumid carapace and less prominent lateral teeth though there is considerable variation among the males in these respects, and the young males often closely resemble the females. The abdomen in young females is much narrower than in the adult form.

This species, the most common spider crab of Monterey Bay, is found abundantly between tides, usually where there is a growth of algae or coralline in company with young *Epialtus productus* which it resembles in habit, being slow of motion and clinging tenaciously to the seaweed when disturbed. The young, together with those of numerous other species, are found among the roots of the eel-grass often in the burrows of the pistol-crab (*Crangon*) which abound in these situations. Specimens were also obtained by dredging in shallow water—5 to 15 fathoms. It is frequently much overgrown with hydroids and coralline.

Color in life red, varying from bright to dark and often closely matching certain of the encrusting corallines. In alcohol the color fades to a dull tan.

The largest specimen in the collection is a male measuring 40 mm. from tip of rostrum to back of carapace and 30 mm. in width between the tips of the posterior teeth (25 mm. between their bases).

Egg-bearing females were obtained in June, July and in the early part of January.

Genus **MIMULUS** Stimpson.

Mimulus Stimpson, Ann. N. Y. Lyc. Nat. Hist., vii, 200, 1860 (Type—*Mimulus foliatus* Stimpson).

Mimulus foliatus Stimpson.

Plate IV, figs. 12-13.

Mimulus foliatus Stimpson, Ann. N. Y. Lyc. Nat. Hist., vii, 200, pl. iii, fig. 1, 1860.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 23, 1900, and synonymy.—Rathbun, H. A. E., x, 173, 1904.

Represented in the collection by numerous specimens, mostly young,

dredged from moderate depths—5 to 12 fathoms. It is found along-shore with *P. richii*, but is less numerous.

There seems to be considerable variation in the shape of the two lateral teeth and in the relative widths at these two points.

"Color a dull purplish, the legs crossed by light bands," Holmes. The young and even mature (egg-bearing) individuals show considerable variation in color, being in general tan or light reddish with the lateral expansions and marks on the cardiac region lighter, in some cases almost white. One specimen had the entire surface of the carapace—except the rostrum—the abdomen and the chelipeds clear white, while the remainder of the legs and the rostrum were bright red. The legs in the majority show a more or less distinct banding. The adults are often partially covered by a growth of bryozoa or sponge.

Genus **LOXORHYNCHUS** Stimpson.

Loxorhynchus Stimpson, Proc. Bost. Soc. Nat. Hist., vi, 84, 1857, Journ. Bos. Soc. Nat. Hist., vi, 451, 1857 (Type—*Loxorhynchus grandis* Stimpson).

Key to species.

- a. Carapace with numerous nearly equal tubercles, sparingly hairy or smooth in adult. *L. grandis*
- aa. Carapace with 9 to 12 very prominent tubercles; covered with a short thick felt-like coat of hair. *L. crispatus*

Loxoryhynchus grandus Stimpson.

Plate V, fig. 14.

Loxoryhynchus grandus Stimpson, Proc. Boston Soc. Nat. Hist., vi, 85, 1857.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 29, 1900, and synonymy.—Rathbun, H. A. E., x, 175, 1904.

Represented in the collection by two large males brought in by Monterey fishermen from "deep water." The fingers of the cheliped gape at the base, and there is a large blunt tooth on the dactyl which projects into this space. The measurements of the specimen figured are as follows:

Total length of carapace.....	165 mm.
Total width of carapace.....	123 "
Length of cheliped (approximately).....	232 "
Length of first ambulatory leg (approximately).....	268 "

***Loxorhynchus crispatus* Stimpson.**

Plate V, fig. 15.

Loxorhynchus crispatus Stimpson, Jour. Boston Soc. Nat. Hist., vi, 453, pl. xxii, figs. 2, 3 and 4, 1857.—Rathbun, Proc. U. S. Nat. Mus., xvii, 74, 1894.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 30, 1900.—Rathbun, H. A. E., x, 175, 1904.

A series of 30 specimens (9 young) correspond well with Holmes's description, to which, however, the following points may be added. The anterior branchial tubercle is double, due to a smaller tubercle arising from the anterior internal flank. About midway between the posterior branchial tubercle and the cardiac-intestinal ridge, and lying nearly parallel to the latter, is a short slightly curved ridge or elongated tubercle. The tubercles of the carapace and of the legs, appearing, according to Miss Rathbun, "hemispherical with small shining points emerging," are in young or perfect specimens topped by a bunch of long clavate setæ, stouter and longer than those of the rostrum and uncurved. Similar setæ are found along the angles of the somewhat prismatic legs, along the posterior margin of the carapace, about the coxæ of the legs, and along the edge of the abdomen in the female.

The chelipeds of the male, as stated by Miss Rathbun, gape at the base and the dactyl is provided with a blunt tooth which projects into this space, while those of the female meet throughout their length.

The young (13 to 22 mm.) differ considerably from the adults, the inner layer of plush-like hair being less marked, while more long hairs are scattered over the surface; the preorbital spine is more flattened at the base and directed more nearly horizontal, while the distance between their tips and the length of the rostrum in proportion to the length of the carapace is much greater than in the adult. Width between tips of preorbital spines is to length of the carapace as 1 is to 3 in young and as 1 is to 5 in an old male. The tubercles in the young are less pointed and prominent than in the adult. Intermediate stages, however, connect all these characters. The horns of the rostrum are more divergent in the female than in the male.

The color of specimens in alcohol ranges from reddish brown to tan; the carapace after removal of the hair often shows red markings, especially about the tubercles.

Measurements of largest male in collection (the specimen figured) :

Total length of carapace.....	115 mm.
Total width of carapace.....	84 “
Length of cheliped (approximately).....	233 “
Length of first ambulatory leg (approximately).....	161 “

This species is found from between tides to a depth of 50 ft. It is commonly known as the “moss crab” from the fact that it is generally completely covered with algæ, hydroids, bryozoa, ascidians, and the like so as to be “scarcely recognizable as a crab at all.” It is, as might be expected, very sluggish in all its movements.

Genus **CHORILIA** Dana.

Chorilia Dana, Am. Journ. Sci., (2), xi, 269, 1851; Crust. U. S. Expl. Expd., part 1, 91, 1852 (Type—*Chorilia longipes* Dana).

Chorilia longipes Dana.

Plate VI, fig. 16.

Chorilia longipes Dana, Am. Journ. Sci., (2), xi, 269, 1851.

Hyastenus (Chorilia) longipes Holmes, Occas. Papers Calif. Acad. Sci., vii, 33, 1900.

Chorilia longipes Rathbun, H. A. E., x, 174, 1904.

No specimens of this species from a point nearer than San Diego are in the collection, although it is in all probability found in the bay.

Genus **SCYRA** Dana.

Scyra Dana, Amer. Journ. Sci. and Arts, ser. 2, xi, 269, 1851; Crust. U. S. Expl. Expd., xiii (i), 80, 1852 (Type —*Scyra acutifrons* Dana).

Scyra acutifrons Dana.

Plate VI, fig. 17.

Scyra acutifrons Dana, Am. Journ. Sci., (2), xi, 269, 1861.—Rathbun, Proc. U. S. Nat. Mus., xvi, 88, 1893.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 41, 1900.—Rathbun, H. A. E., x, 175, 1904.

This species (a series of about 30) shows, as stated by Holmes and Rathbun, great variation in the tuberculation of the carapace and in the form of the rostrum, as the following comparison of two large males of approximately the same size will show.

Total length.....	.... 37 mm. ....	..... 39 mm.
Width at posterior branchial tubercle.....	.... 27 " ....	..... 27 "
Width between margins of carapace .....	.... 27.5 " ....	..... 26 "
Rostrum, notch to tip....	.... 4 " ....	..... 6 "
" tip to base of preocular spine .....	.... 7 " ....	..... 10.5 "
" greatest width..	.... 7 " ....	..... 9 "
Branchial tubercles.....	Posterior prominent, anterior a tuberculated knob.	United in a heavy ridge overhanging posteriorly the edge of carapace.
Anterior median tubercle..	Almost obsolete.	Sharp and prominent.
Cardiac tubercle.....	A smooth elevation	A hemispherical, tuberculated knob.

The young males are smoother than the adults and have narrower and more divergent horns to the rostrum, while the females have at times carapaces which are little more than undulated. The anterior external angle of the basal antennal joint is somewhat produced but seems hardly to form a spine as stated by Holmes. The "two spines or teeth on the outer margin" behind this are seldom prominent, the anterior being little more than an undulation of the margin.

This species is found from between tides to 20 fathoms, and like most of the spider crabs is generally so overgrown with sponges and other forms as to conceal the color.

All of the egg-bearing females are dated June.

Genus RHODIA Bell.

Rhodia Bell, Proc. Zool. Soc. Lond., 169, 1835; Trans. Zool. Soc. Lond., vol. ii, 43, 1841 (Type—*Rhodia pyriformis* Bell).

Rhodia parvifrons (Randall).

Plate VII, fig. 18.

Herbstia parvifrons Randall, Journ. Acad. Nat. Sci. Phila., viii, 170, 1839.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 38, 1900.

Herbstia (*Herbstiella*) *campacantha* Holmes, *op. cit.* 37, and synonymy.

Rhodia parvifrons Rathbun, H. A. E., 175, 1904, and synonymy.

Five specimens of this species have been obtained by the writer during 1908, all from a large tide-pool just south of the Point Pinos lighthouse. These agree well with Holmes's description except that the

median tubercles are apparently less prominent, and that part of the tubercles, especially those in the posterior region, are tipped with setæ. All were much covered with sponges of various kinds and the like. The color of the carapace is a light tan mottled with dark brown; the ambulatory legs are barred with reddish brown, and the chelipeds, with the exception of the light tips of the fingers, are a still more pronounced red.

This species has not been before recorded north of San Pedro.

Genus **CHIONOECETES** Kröyer.

Chionoecetes Kröyer, Naturh. Tidskrift, (1), 2, 249, 1838 (Type—*Chionoecetes opillio* (Fabricius)).

Chionoecetes tanneri Rathbun.

Plate VII, fig. 19.

Chionoecetes tanneri Rathbun, Proc. U. S. Nat. Mus., xvi, 76, pl. iv, figs. 1-4, 1893.
—Holmes, Occas. Papers Calif. Acad. Sci., vii, 40, 1900.—Rathbun, H. A. E., x, 174, 1904.

Though there are no specimens in the University collection which are known definitely to have come from Monterey Bay, this species was obtained, according to Dr. Fisher, in large numbers by the "Albatross" while dredging at Monterey.

Superfamily BRACHYRHYNCHA

Family CANCRIDÆ.

Genus **CANCER** Linnæus.

Cancer Linnaeus, Syst. Nat. ed. 10, vol. i, 625, 1758.

The genus *Cancer* appears to reach its highest development in the north Pacific, and on the west coast of the United States is represented, according to Miss Rathbun, by nine species. One of these—*C. magister*—is the common market crab of the whole coast, and with the exception of one or two other species of *Cancer*—*C. productus*, *C. antennarius*—is the only crab used as an article of food, so that the genus assumes considerable economic importance. Seven species have been reported from Monterey Bay: *productus*, *magister*, *gracilis*, *gibbosulus*, *jordani*, *antennarius* and *oregonensis*. I have obtained all these with the exception of *oregonensis*.

As considerable interesting material was available in this genus I have included as far as possible all the species found on this coast in the keys: specimens of all of which with the exception of *amphioetus* have been examined. For six species—*productus*, *jordani*, *gracilis*, *gibbosulus*, *antennarius*, and *anthonyi*—sufficient young material was at hand to render possible the identification of immature specimens down to a size, in most cases, of 5 mm. in width. A key is given for those measuring 20 mm. and less in width, as the key to adults will not hold in many cases for the young and it is often very desirable to be able to place immature specimens, some of which are very liable to confusion with the adults of smaller species. Satisfactory identification of small forms will not be possible in all cases without material for comparison; in fact the young of several species could be placed only through a complete growth series, a study of which disclosed some very interesting facts.

Although *gracilis* and *gibbosulus* differ so widely in the adult or even in specimens measuring 20 mm., at a size of 5 mm. they are almost indistinguishable, the young of *gracilis* showing the alternately large and small antero-lateral teeth and a well developed tenth tooth, both of which characters are absent in the adult of this species but present in the adult—and young—of *gibbosulus*. The case of *anthonyi* and *jordani* is similar, here the young of *anthonyi* exhibit many of the characters of the adult *jordani*.

It is of course unsafe to rely too much upon the recapitulatory nature of these ontogenetic resemblances, but if even the slightest value is allowed them some very interesting light is thrown on the relationships of this group, promising much to a more extended study. The young of the six species mentioned, with the exception of *productus*, show many characters in common; they are pubescent, the antero-lateral teeth are alternately large and small and have spiny tips, the antennæ are large, stout and hairy, the chelipeds are more or less spiny, the carapace is long in proportion to its width, and the front is proportionally very wide. Some of these characters, such as the greater length of the carapace and the prominence of the front, are undoubtedly connected with the metamorphosis from the larval form, but others, for instance the alternately large and small teeth, which at least in *gracilis* appear immediately on molting from the megalops stage, seem hardly to be in any way connected with the metamorphosis or other ontogenetic changes. Of these five species only two—*jordani* and *gibbosulus*—retain the above mentioned characters in the adult, but here they are well marked. (See figures of these species.) Now *gibbosulus* was the type of the genus *Trichocarcinus*, and these

characters, as pointed out by Miers (Proc. Zool. Soc. London, 1879, p. 34) in speaking of that genus, indicate an undoubted relationship with *Telmessus* and *Erimacrus*, so that the placing of these troublesome genera in the Cancridæ, as is done by Miss Rathbun, is distinctly supported by the facts at hand. That *gibbosulus* is a *Cancer* there can be no doubt, in fact on the basis of youthful characters it might easily be considered the most typical of all the Pacific Coast species.*

It is unfortunate that no young specimens of *oregonensis* were available, as light might have been thrown on the relationship of this interesting form which differs so widely from other *Cancers*. As before mentioned, the young of *productus*, even in the smallest specimens at hand—6 mm. wide—show no pubescence and no spiny tips or alternate arrangement of the antero-lateral teeth. The antennæ, though proportionally larger than in the adult, are not so large as in the other species and are not bushy; the front moreover retains its characteristic appearance and does not resemble that of any other species examined. Its relation to the other west coast *Cancers* would, therefore, appear to be rather distant.

KEY TO SPECIES OF CANCER FOUND ON WEST COAST.

- a. Antero-lateral and postero-lateral margins meeting at a distinct angle; carapace widest at 9th (sometimes 8th) tooth. 9, 10 or 11 teeth.
 - b. Front markedly produced, formed of 5 subequal teeth.

C. productus
 - bb. Front not markedly produced, formed of 5 unequal teeth; outer teeth larger and more widely separated from the 3 median teeth than these from each other.
 - c. Antero-lateral teeth low (projecting less than 1-3 the length of base) or irregular, not spiny-pointed; fingers of chelipeds not dark-tipped; merus of outer maxilliped elongated, rounded anteriorly. (These characters, except those of the fingers of chelipeds, do not hold in very small specimens.)

* As this paper is going to press I find an article by J. T. Cunningham in the Proceedings of the Zoological Society of London (1898, p. 204) in which he figures an early stage of the common European *Cancer* (*C. pagurus*) and points out the close relationship to the young of *Atelecyclus* which he considers should be included in the Family Cancridæ. The figure of the youngest shows the alternation of large and small antero-lateral teeth mentioned above as characteristic of most species. This seems to furnish an additional proof of the wisdom of extending the genus *Cancer*.

- d.* Carpus of cheliped with a single spine above at distal end; dactyls of ambulatory legs, especially those of last pair, much flattened. *C. magister*
- dd.* Carpus of cheliped with 2 spines, one above at distal end and a second below this on inner angle; dactyls of ambulatory legs slender, not flattened. *C. gracilis*
- cc.* Antero-lateral teeth not low (projecting more than 1-3 the length of base), often spiny pointed; fingers of cheliped dark-tipped; merus of outer maxilliped not elongated, truncated anteriorly.
- d.* Carpus of cheliped with 2 spines, one above at distal end and a second below this on inner angle; hand roughened and armed above with 2 or more spines (sometimes inconspicuous).
- e.* Antero-lateral teeth acute, strongly produced, alternately large and small; carapace pubescent.
- f.* Tenth antero-lateral tooth conspicuous, 11th present; dactyl of cheliped spiny. *C. gibbosulus*
- ff.* Tenth antero-lateral tooth inconspicuous, 11th not present; dactyl of cheliped not spiny. *C. jordani*
- ee.* Antero-lateral teeth broadly triangular, not strongly produced, subequal; carapace not pubescent. *C. amphioetus*
- dd.* Carpus of cheliped with a single spine above at distal end; hand smooth or granulated, without spines.
- e.* Carapace widest at 8th antero-lateral tooth, 11th distinct; dark color on dactyls of cheliped reaching more than $\frac{1}{2}$ the length of outer margins; under parts spotted or blotched with reddish. *C. antennarius*
- ee.* Carapace widest at 9th antero-lateral tooth, 10th inconspicuous; dark color on dactyls of chelipeds reaching less than $\frac{1}{2}$ the length of outer margins; under parts of uniform light color. *C. anthonyi*
- aa.* Antero-lateral and postero-lateral margins not meeting at a distinct angle; carapace widest at 7th or 8th tooth; 12 or 13 teeth. *C. oregonensis*

KEY TO SPECIES OF THE GENUS *CANCER* EXAMINED.

(Young of 20 mm. and less in width.)

- a. Front markedly produced, formed of 5 subequal teeth, of which the median is the most advanced; antero-lateral teeth never spiny pointed; carapace never pubescent. *C. productus*
- aa. Front not markedly produced, formed of 5 unequal teeth, the outer teeth larger and more widely separated from the three median teeth than these from each other; antero-lateral teeth spiny-pointed; carapace generally pubescent.
 - b. Tenth antero-lateral tooth (counting that next the eye as one) prominent, usually spiny pointed.
 - c. Carpus of cheliped with 2 prominent spines (not counting that at hinge) one above at distal end, and the second below it at inner angle.
 - d. Tenth antero-lateral tooth projecting laterally beyond carapace as seen from above; carapace comparatively smooth. *C. gracilis*
 - dd. Tenth antero-lateral tooth projecting dorsally, not reaching beyond outline of carapace as seen from above; carapace markedly areolated. *C. gibbosulus*
 - cc. Carpus of cheliped with a prominent spine above at distal end; below this at inner angle an inconspicuous spine sometimes present. Under parts usually with red markings. *C. antennarius*
 - bb. Tenth antero-lateral tooth absent or represented by a rudiment.
 - c. Carapace finely pubescent, antero-lateral teeth alternately large and small; carpus of cheliped with 2 spines, one above at distal end and a second less conspicuous spine below this at inner angle. *C. jordani*
 - cc. Carapace smooth or sparsely and coarsely pubescent, antero-lateral teeth alternately large and small only in very young specimens (5 mm. or less); carpus of cheliped with a spine above at distal end and only in very young a second minute spine below this at inner angle. *C. anthonyi*

Cancer productus Randall.

Plate VIII, figs. 20-24.

Cancer productus Randall, Journ. Acad. Nat. Sci. Phila., viii, 116, 1839.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 47, 1900.—Rathbun, H. A. E., x, 175, 1904.

This species is represented by numerous specimens, as it is one of the most common of the large shore crabs of Monterey Bay. Age differences, as noted by various writers, are conspicuous. The most noteworthy are in the relative length and width of the carapace and the width of the front, and as the age differences in this species are in general similar to those of the genus and show of how little value are such specific characters as the proportion of the front to the total width of the carapace, a considerable series of measurements is given. The frontal and antero-lateral teeth in the adult are more sharply defined and have more acute tips than in the young, and on the other hand the crests on the head of the young are more acute than those of the adult. Another age difference which I have not seen mentioned is that of the length of the external maxillipeds. In the adult they overlap the endostome to a marked degree, and this has been used as a family character. In the young, however, the maxillipeds are shorter and reach only to the endostome, as is the case with many of the Pilumnidæ—*Xanthias*, *Cycloxanthops*, and others.

The adult color of a "dark red above, below, a dirty white" or "yellowish white" is not invariable, though there are no striking differences; some adults show a light red above due to minute red spots, not so numerous as in the case of the darker color, on a yellowish ground. The longitudinal colored lines of the immature specimens as described by Holmes is not the invariable youthful coloration; various mottled patterns are also found and occasionally the red of the adult.

The chief sexual difference seemed to be the greater convexity of the female carapace, which is quite marked in large specimens.

All specimens listed in the following table, except as otherwise stated, are from Pacific Grove.

The breadth of the carapace was measured at the eighth antero-lateral tooth, the inter-orbital width was measured between the inner supra-orbital fissures; the convexity was the height of the center of the carapace above the tips of the eighth antero-lateral teeth, and this per cent is calculated on the basis of total width=100; all other per cents have the total length as 100; owing to the difficulty of measurement, the convexity is less reliable than the other measurements.

TABLE OF MEASUREMENTS OF CANCER PRODUCTUS.

Sex	Carapace			Interorbital width		Width of second abdominal segment		Convexity		Remarks
	Length	Breadth								
	mm.	mm.	%	mm.	%	mm.	%	mm.	%	
immature	4.0	4.3	108	2.4	60	1.0	25	..	..	color whitish
"	4.0	4.4	110	2.4	60	1.0	25	..	..	" "
"	4.3	4.5	105	2.5	58	1.0	24	..	..	" "
"	* 5.0	5.8	115	2.8	55	1.3	25	..	..	reddish
"	5.3	6.5	123	3.0	57	1.3	25	..	..	brown
"	* 5.5	6.3	114	2.8	51	1.3	23	..	..	whitish
"	5.6	6.7	120	3.1	55	1.6	29	..	..	slate
"	* 6.5	8.0	124	3.3	50	1.5	24	..	..	reddish
"	6.6	8.3	126	3.5	53	1.7	26	..	..	light
"	6.7	8.4	125	3.7	55	1.9	28	..	..	longitudinal
"	7.9	10.0	126	4.0	51	2.0	25	..	..	light
"	9.0	12.0	133	4.4	49	2.3	26	..	..	"
"	9.0	12.3	137	4.4	49	2.3	26	..	..	"
"	9.1	12.6	139	4.4	48	2.5	28	..	..	white
female	17.0	24.5	144	7.5	44	3.5	21	2.0	8	light-striped
"	23.0	34.0	148	9.0	39	5.0	22	4.0	12	slate
"	24.0	36.5	152	9.5	40	5.5	23	4.0	11	light
"	25.0	37.0	148	10.0	40	6.0	24	3.5	9	large red spot
"	25.0	37.0	148	10.0	40	6.0	24	4.0	11	slate
"	33.0	50.0	152	12.0	36	8.5	26	4.5	9	red mottled
"	37.0	56.0	154	13.5	36	9.5	26	5.5	10	reddish
"	40.0	62.0	155	14.0	35	10.0	25	6.0	10	tan
"	41.5	65.0	157	14.5	35	11.0	27	5.0	12	faintly striped
"	54.5	86.5	159	18.0	33	14.0	26	..	..	dark red
"	66.5	105.5	158	20.0	30	19.0	29	7.5	7	" "
"	78.5	127.0	162	23.5	30	24.5	31	15.5	20	" "
male	20.0	28.5	143	8.0	40	4.0	20	2.0	10	tan
"	22.5	34.2	153	9.1	40	6.6	29	..	..	slate with stripe
"	25.0	38.0	152	10.0	40	6.0	25	4.0	11	faintly striped
"	25.0	38.5	154	9.5	38	5.0	20	4.0	10	" "
"	26.5	40.5	153	10.5	40	6.0	23	3.5	9	mottled
"	27.5	41.0	150	11.0	40	6.0	22	3.0	7	faintly striped
"	29.0	44.0	152	11.0	38	6.5	25	3.0	7	striped
"	29.0	44.0	152	11.0	38	6.5	25	3.5	8	mottled, dark
"	33.0	52.0	158	12.5	38	7.5	23	6.0	12	
"	37.5	58.0	155	14.0	37	9.0	24	5.5	9	dark red
"	37.5	59.0	157	14.0	37	9.0	24	..	..	striped, light
"	66.0	108.0	164	21.0	32	16.0	24	..	..	dark red
"	73.5	121.5	165	22.0	30	18.0	25	9.5	8	" "
"	82.0	136.0	166	25.0	31	20.0	24	10.5	8	" "
"	103.0	171.0	166	30.0	29	25.0	24	20.0	12	" "
"	103.0	173.5	168	31.0	30	27.0	26	12.0	7	" "

* These three specimens are from Puget Sound.

Cancer magister Dana.

Plate IX, fig. 25.

Cancer magister Dana, Proc. Acad. Nat. Sci. Phila., viii, 78, 1852.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 50, 1900, and synonymy.—Rathbun, H. A. E., x, 177, 1904.

This species is common in the Monterey markets, but has not been obtained in any of the dredging done by the laboratory.

Cancer gracilis Dana.

Plate IX, figs. 26-28.

Cancer gracilis Dana, Proc. Acad. Nat. Sci. Phila., vi, 73, 1852.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 52, 1900, and synonymy.—Rathbun, H. A. E., x, 177, 1904.

Cancer gracilis is represented by a considerable number of specimens, both young and adult, all obtained by dredging, though in Puget Sound it is an abundant shore crab. On several occasions the young of this species has been found in considerable numbers clinging to the sub-umbrella of various medusæ. These have all been of small size—5 to 10 mm.—but it was not until the summer of 1908 that younger stages were found. On one occasion a number of medusæ were collected and in examining these many very young crabs were obtained and a smaller number of megalops. Some of these were kept alive until the molt to the young crab stage took place, so that there can be little doubt that the specimens were really the megalops of *gracilis*. Later megalops were obtained from other species of medusæ, and crabs of a slightly larger size than those found on the jelly-fish were dredged in considerable numbers; it would appear, therefore, that in the case of *gracilis*, at least a considerable number of individuals pass that portion of their life history from the end of the free-swimming stage, probably early megalops, until reaching a size of 15 to 20 mm. clinging to medusæ, after which they drop to the bottom and live in the manner of the adult. I have found no other species than *gracilis* on medusæ though Miss Rathbun reports one specimen of *jordani* from the same situation. It would be interesting to know if this form of life history were universal with *gracilis* and if it were common in any other species.

Color in life olive overlaid with minute reddish brown spots, which are more numerous on the teeth of the antero-lateral margin and on the

front and give to the whole a brownish tinge; edges of teeth, under parts and greater portion of legs, yellowish. There is little variation in color among individuals and but small difference between fresh and alcoholic specimens.

Cancer gibbosulus (de Haan).

Plate X, fig. 29.

Corystes (Trichocera) gibbosula de Haan, Fauna Japon., 45, pl. ii, fig. 4, pl. xiii, fig. 3, 1835.

Tricocarcinus gibbosulus Miers, Proc. Zool. Soc. London, 34, 1879.

Cancer gibbosulus Rathbun, Proc. U. S. Nat. Mus., xxi, 581, 1898.—Rathbun, H. A. E., x, 176, 1904.

This species is represented in the collection by several specimens, the largest measuring 35.5 by 25.5 mm., all obtained by dredging at moderate depths—10 to 20 fathoms.

As no figures or detailed descriptions are easily available, the large male whose measurements are given above is figured and the following description given.

Carapace markedly areolated, the most conspicuous depressions running back from the outer angle of the eye nearly to the posterior margin of the carapace and enclosing between them the gastric, cardiac, and intestinal regions. Gastric region divided by a groove beginning at the median tooth of front, passing back and dividing like an inverted Y, the arms of which form the anterior boundary of the cardiac region. The lateral margins of the cardiac region converge posteriorly; from the anterior end where they meet the arms of the Y, a pair of rather shallow grooves run to the antero-lateral margin of the carapace, ending between the fifth and sixth teeth. Carapace sparsely pubescent, hairs rather conspicuous and harsh. Antero-lateral margin, including outer angle of orbit, with 9 strongly produced and forward curving teeth, all except first two tipped with spines. Behind these on postero-lateral margin a well marked tenth tooth directed upward and not laterally and a distinct spine representing the eleventh. A conspicuous raised ridge along the postero-lateral border and another across the posterior margin. Front with 5 acute teeth—not counting the supra-orbital—the three median of which are the smaller and are separated from the tooth at inner angle of eye by a distance rather greater than that occupied by the three. Supra-orbital tooth acute, margin of orbit prominent, eyes and stalks normal. Antennæ large, stout, and conspicuously hairy, about equaling width of front; outer

angle of basal joint produced, acute and plainly visible from above, reaching about as far forward as median tooth of front.

Merus of maxillipeds abruptly truncated, inner angle slightly produced, inner margin with a conspicuous tooth below the articulation of palp. Exognath stout, reaching to end of merus.

Chelipeds hairy, carpus with a conspicuous spine near hinge, another inside of this terminating a slight ridge and reaching well forward, and a third below this on the inner side. This latter tooth is more conspicuous than in any other species with the possible exception of *gracilis*. Upper surface of carpus with a few reddish spines, upper surface of hand with two rows of three to five spines, outer surface with 5 costæ marked with hair and small spines, upper margin of dactyl spiny. Fingers meeting along most of their length, armed with conspicuous teeth. Ambulatory legs hairy, dactyls slightly longer than the propodi, straight, tipped with nearly straight corneus spines.

Abdomen of 7 joints, regularly tapering from the third to the tip; terminal joint long and slender, reaching nearly to the anterior border of the coxæ of the chelipeds.

Color whitish marked with irregular but symmetrically disposed reddish blotches, tips of fingers of chelipeds black, ambulatory legs light banded with red.

Since writing the above description another and still larger specimen of this species, also dredged from about 10 fathoms in Monterey Bay, has come into my hands. As it differs somewhat from the preceding it seemed well to add the following points. Although the proportion of width to length in the carapace is almost exactly that of the one described (46 by 32.5 mm.), it appears wider, as the lateral teeth are much shorter. The areolation is distinct but rather less deep than in the former case, the pubescence is similar though a trifle more dense, and there is a tendency towards tufts of setæ and granules on the prominences of the carapace which is barely indicated in the other. The antero-lateral teeth are similar but less acute and projecting and with more pronounced secondary denticulations. The teeth of the front are less acute and prominent, especially the supra-orbital. Chelipeds similar but even more markedly spiny. General color reddish, due to light red marblings on a whitish ground.

As pointed out before, the young of this species closely resemble the young of *C. gracilis*. The large specimen at hand shows an almost equally striking resemblance to the hairy form of *C. antennarius* noted under that species, lending some color to the supposition that that form may repre-

sent a hybrid. The specimen at hand and the hairy extreme of *antennarius* figured in plate XI, fig. 32, resemble each other very closely in the areolation and pubescence of the carapace and in the appearance of the antero-lateral teeth, differing in the two former characters markedly from the typical *antennarius*. The frontal regions are similar. The greatest differences lie in the chelipeds and in the dactyls of the ambulatory legs. Although the hand and carpus of this specimen of *antennarius* is much more spiny than in the typical form, and thus approaches *gibbosulus*, yet it is less spiny than in the specimen of *gibbosulus* at hand, particularly in the case of the two at the inner angle of the carpus, which are much less prominent and acute. The dactyls of the ambulatory legs in the specimen of *antennarius* are of the typical form for that species, and are shorter, stouter and more curved than are those of *gibbosulus*. In the specimen of *antennarius* the dark color of the dactyl of the cheliped is less extensive than in *gibbosulus*. The characteristic red spotting of the under surface of *antennarius* is also absent in the specimen of *gibbosulus*.

Cancer jordani Rathbun.

Plate X, fig. 30.

Cancer jordani Rathbun, American Nat., xxxiv, 133, 1900.—Rathbun, H. A. E., x, 176, 1904.

This species is represented by over 25 specimens, mostly collected along shore, though a few were dredged. They range in size from 5 to 25 mm. in length, and as the largest specimen recorded by Miss Rathbun is 20 mm. in length, a figure is given of the largest individual and a description partly in the words of Miss Rathbun (H. A. E., x, 176). The series includes two egg-bearing females, the only ones which I have seen; their size, as seen from the table of measurements, is below that of many of the other specimens, both male and female.

Carapace more than one and one-fourth times as wide as long. The proportion in the large male here described is 1.33 to 1, but this varies with age: see table of measurements. (The statement "Length of carapace one and a fourth times width" is obviously a misprint, as the length is later given as 15.5 and the width as 19.5 mm.) "Surface hairy and "covered with small crowded scabrous granules. Regions indicated by "narrow and shallow depressions. Teeth of front and lateral border not "thickened as in *antennarius*; inner orbital tooth very slightly produced;

"margin of upper orbital tooth almost transverse, scarcely dentiform. "Lateral teeth separated to their bases, tips spiniform and curved forward; second, fourth, sixth, and eighth smaller than the others (the "outer orbital tooth reckoned as the first); ninth tooth scarcely more "prominent than eighth. No postero-lateral tooth." The alternation in size of the antero-lateral teeth varies with age, being very noticeable in the small specimens and hardly evident in this the largest of the series. It also appears, as stated elsewhere, in the young of other species. The tenth (postero-lateral) tooth is indicated in the present specimen, and less conspicuously in other younger ones, by a slight gap in the small spines marking the raised postero-lateral margin. "Basal antennal tooth and that of adjoining margin acute," but less produced than in *gibbosulus*. "Movable part of antennæ [nearly] half as long as carapace." In many of the other specimens the antennæ fall considerably short of this length. "The outer maxillipeds overlap considerably the basal joint of the antennæ; merus longer than wide;" obliquely truncated, the inner angle the more advanced, corners rounded. "The palms of the chelipeds have two superior and five external carinæ fringed with hair." The superior carinæ are marked with several small spines besides the hairs. "On the prehensile edges of the fingers the dark color runs from the proximal end of the fingers nearly to the tips, but on the outer edges the dark color begins near the middle of the fingers." In the key given by Miss Rathbun in the *American Naturalist*, *jordani* falls under the division, "Color on the fingers extending from the tip not more than half the length of the fingers." In the specimen before me and in most of the collection the color extends from the tip of the dactyl distinctly more than half way to its base on the outer edge.

The measurements of this the largest of the collection and of a series of smaller specimens are here given:

SEX	LENGTH	WIDTH	INTER-ORBITAL WIDTH	ANTENNAL LENGTH
male	25.4 mm.	33.4 mm.	10.3 mm.	13.0 mm.
"	22.0	28.5	9.0	8.0
"	19.0	24.6	8.0	8.0
"	14.0	17.0	6.0	6.5
female	18.5	23.7	8.0	8.0
"	16.0	20.0	7.3	7.5
"	11.2	14.3	5.0	5.0 (carrying eggs)
"	10.2	12.5	5.0	5.0
"	10.5	12.5	5.0	5.0 (carrying eggs)

(**Cancer amphioetus** Rathbun.)

Trichocarcinus dentatus Miers, Proc. Zool. Soc. London, 34, 1879.

Cancer amphioetus Rathbun, Proc. U. S. Nat. Mus., xxi, 582, 1898.—Rathbun, H. A. E., x, 175, 1904, and synonymy.

No specimens of this species are in the University collection. Its range on the Pacific coast—Magdalena Bay to San Diego Bay—and its occurrence in Japan, make it at least possible that it will be found farther north, as has proved the case with *gibbosulus*, and I have included it in the keys for completeness.

Cancer antennarius Stimpson.

Plate X, fig. 31. Plate XI, fig. 32.

Cancer antennarius Stimpson, Proc. Calif. Acad. Sci., 1, 88, 1856.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 49, 1900, and synonymy.—Rathbun, H. A. E., x, 176, 1904.

This is one of the largest and most common crabs along shore at Pacific Grove and is represented by numerous specimens ranging in width from less than 10 mm. to 120 mm.

There is considerable variation in this species and apparently a tendency toward two types, the extremes of which might readily be taken as separate species. By far the greater number—which I would consider typical *antennarius*—have a smooth carapace devoid of hair except in the very young—15 mm. and less in width—where there are a few coarse hairs. A small number show a tendency toward hairiness and roughness of the hand, the extreme type of which, represented by a young female measuring 46 by 50 mm., is shown in figure 32, Pl. XI. In this the whole carapace is densely pubescent (typical specimens of half the size show a perfectly bare carapace) and on the summits of the areolations, which are more marked than in the typical form, there are bunches of larger and stouter hairs. The granulations on these elevations are coarser than on the rest of the carapace and in some cases pass into small spines. The antero-lateral teeth do not differ markedly from the typical form except in being more thickened and in having the teeth spiny pointed. The frontal teeth are more acute and thicker than is common in *antennarius*, especially those lying on either side of the median tooth. The tips of the basal joint and of the adjoining tooth on the lower orbital margin are more acute than in typical *antennarius* of the same size.

The chelipeds and ambulatory legs are pubescent, as is the case with the carapace. The carpus of the chelipeds is marked with several costæ bearing low spines and rows of hairs; these costæ are generally indicated in the typical form by a line of slightly coarser granulations. There is an acute tubercle above the hinge, a strong spine at the inner angle and a well marked spine below this. These spines are present in some typical *antennarius* of the same size, but the lower spine is more generally lacking and never of as great size. The hand is marked with two superior and five external carinæ, all formed of rows of hairs and spines, the spines in the upper carinæ being much longer and more pronounced. In typical *antennarius* of the same size these carinæ are more or less well marked by rows of granulations.

This specimen is, as I have said, the extreme of divergence from the typical form; other smaller individuals show the same pubescence, some have the same extreme type of areolation, notably a larger female from San Diego, the only one not from Monterey Bay here considered, many young show roughness of the hand, but no other specimen combines as many of these characters.

The total of these variations from the typical form of *antennarius* might merit specific distinction were it not for certain other facts. All specimens in which I have noticed these characters in any marked degree are immature females. Though they differ from typical forms of the same size, and therefore presumably of similar age, yet certain of the characters, chiefly the roughness of the hand and the pubescence of the carapace, vary with age in the typical form, being more apparent in the young, so that these differences though apparently much greater than those due to age, cannot be said to be of a dissimilar kind. Again, in the typical adult, the female has a more convex and deeply areolated carapace than the male, which gives rise to a suspicion that the difference in this character may be, in part, sexual.

Miss Rathbun has informed me that she has examined very hairy specimens of about the size described—40 and 50 mm.—from La Jolla and San Diego which she considered as a variety of *antennarius*. Sufficient material may establish this variety, but the collection at hand does not seem to warrant it.

The color of live specimens is fairly uniform and undergoes little change in alcohol. The general shade is a dark red usually more or less mottled with a lighter, more yellowish tinge; the under parts are yellowish white spotted with red, a coloration not found in any other species of *Cancer* examined.

(*Cancer anthonyi* Rathbun.)

Plate XI, fig. 33.

Cancer anthonyi Rathbun, Proc. Biol. Soc. Wash., xi, 111, 1897.—Rathbun, Am. Nat. xxxiv, 134, 1900.—Rathbun, H. A. E., x, 176, 1904.

I have examined a series of four specimens from San Diego. The species is not recorded north of Long Beach, Cal., and I have included it merely for completeness.

***Cancer oregonensis* (Dana).**

Plate XI, fig. 34.

Trichocera oregonensis Dana, Proc. Acad. Nat. Sci. Phila., vi, 86, 1852.—Dana, Crus. U. S. Exp. Exped., i, 299, 1852.
Trichocarcinus oregonensis Holmes, Occas. Papers Calif. Acad. Sci., vii, 54, 1900.
Trichocarcinus walkeri Holmes, *op. cit.* 53.
Cancer oregonensis Rathbun, H. A. E., x, 178, 1904, and synonymy. . .

“Aleutian Islands to Lower California” Holmes. I have examined specimens of this species, but none which I know to have come from Monterey Bay.

Family PORTUNIDÆ.**Genus PORTUNUS Fabricius.**

Portunus Fabricius, Entom. Sys. Suppl., 325, 1798.
Lupa Leach, Edin. Encyc., vii, 390, 1814.
Lupania Rafinesque, Amer. Monthly Mag., iii, 272, Aug. 1818.
Neptunus de Haan, Fauna Japon., 3 and 7, 1833 (Type—*Portunus pelagicus* (Linn.)).

***Portunus xantusii* (Stimpson).**

Plate XII, fig. 35.

Achelous xantusii Stimpson, Ann. N. Y. Lyc. Nat. His., vii, 222, 1860.
Portunus xantusii Holmes, Occas. Papers Calif. Acad. Sci., vii, 71, 1900 and synonymy.—Rathbun, H. A. E., x, 179, 1904.

“Except for a single specimen taken by the *Albatross* in Puget Sound, this species is not known north of San Pedro, California” (Rathbun). I have seen no specimen from Monterey Bay.

Family PILUMNIDÆ.

KEY TO GENERA OF THE FAMILY PILUMNIDÆ.

- a. General shape of carapace transversely oval, division between antero-lateral and postero-lateral margins not sharp, latter curved; front not markedly deflexed. *Cycloxanthops*
- aa. General shape of carapace not oval, antero-lateral and postero-lateral margins meeting at an angle, latter nearly straight; front much deflexed.
 - b. Front divided by a closed fissure. *Lophopanopeus*
 - bb. Front divided by an open rounded notch. *Xanthias*

Genus **CYCLOXANTHOPS** Rathbun.

Cycloxanthus A. Milne Edwards, Ann. Sci. Nat. (4), xx, 278, 1863.

Cycloxanthops Rathbun, Proc. Biol. Soc. Washington, xi, 164, 1897 (Type—*Cycloxanthops sexdecimdentatus* (Edwards & Lucas)).

Cycloxanthops novemdentatus (Lockington).

Plate XII, fig. 36.

Xanthodes? novem-dentatus Lockington, Proc. Calif. Acad. Sci., vii, 32, 1877.

Cycloxanthops novem-dentatus Holmes, Occas. Papers Calif. Acad. Sci., vii, 56, 1900.

Cycloxanthops novemdentatus Rathbun, H. A. E., x, 180, 1904.

Represented in the collection by several specimens one of which was obtained by W. F. Allen. The general color in life is a dull reddish brown showing traces of purple at the posterior part of the carapace and still more strongly on the ambulatory legs and below, thus somewhat resembling *Xanthias taylori*; fingers of chelipeds black with teeth along inner margins white. One young specimen shows the tendency to white markings so common in the young of *Lophopanopeus heathii*.

This species has not previously been reported north of San Pedro.

Genus **LOPHOPANOPEUS** Rathbun.

Lophopanopeus Rathbun, Bull. Lab. Nat. Hist. State Univ. Iowa, 272, 1898 (Type—*Lophopanopeus bellus* (Stimpson)).

The following key to the species of this genus is taken from Miss Rathbun—Am. Nat. xxxiv, 136.

Key to species.

- a. Hands smooth, without lobes or teeth on upper margin. *L. bellus*
- aa. Hands with one or more lobes or teeth on upper margin.
 - b. Carpus of chelipeds smooth or nearly so. *L. heathii*
 - bb. Carpus of chelipeds very rough.
 - c. Carpus of chelipeds covered with reticulating ridges enclosing pits of irregular shape. *L. leucomanus*
 - cc. Carpus of chelipeds covered with tubercles. *L. diegensis*

Lophopanopeus bellus (Stimpson).

Plate XII, fig. 37.

Xantho bella Stimpson, Ann. Lyc. Nat. His. N. Y., vii, 204, pl. v, fig. 2, 1860.

Lophoxanthops bellus Holmes, Occas. Papers Calif. Acad. Sci., vii, 60, 1900, and synonymy.

Lophopanopeus bellus Rathbun, H. A. E., x, 180, 1904, and synonymy.

Lophopanopeus bellus is recorded from Monterey Bay, but it is with some hesitation that I place here some of the specimens which I have examined. In size, proportions of carapace and ornamentation of hand they correspond very closely with Miss Rathbun's description, but the carpus is exactly that given for *L. lockingtoni*; the granulated ridge at the distal margin and the sulcus behind this being the most obvious difference between these specimens and the more numerous *L. heathii*.

The color in life of this, as of *Lophopanopeus heathii*, is very variable, more so than any other crab found in the bay. Some specimens are almost pure white, while others show various irregular patterns of bluish and dark red or are wholly of the latter color.

Lophopanopeus heathii (Rathbun).

Plate XII, fig. 38.

Lophopanopeus heathii Rathbun, H. A. E., x, 182, 1904, and synonymy.

This is by far the most common species of this genus in Monterey Bay, and is represented in the collection by numerous specimens, all of which agree in having a smooth carpus. The color as before stated is very variable.

Lophopanopeus leucomanus (Lockington).

Lophopanopeus leucomanus Rathbun, H. A. E., x, 182, 1904, and synonymy.

Though recorded from the bay, I am unable to find among a large number of specimens of this genus any corresponding to the description of *leucomanus*. A specimen from San Diego has been examined.

Lophopanopeus diegensis Rathbun.

Plate XII, fig. 39.

Lophopanopeus diegensis Rathbun, Am. Nat., xxxiv, 137, 1900.—Rathbun, H. A. E., x, 184, 1904.

There are 15 specimens of this species in the collection all dredged from moderate depths, 10 to 15 fathoms. Many of the series, including some of the smallest, are egg-bearing females, indicating that the adult size is much less than that of *L. heathii*. All agree well with Miss Rathbun's description and figure though the carpal crests of the ambulatory legs are in some cases longer and more acute than represented. Color in life, dull brown or blackish occasionally tinged with red, but never conspicuously marked as in *L. heathii*.

This species has not been previously reported from north of San Diego and off Pt. Conception.

Genus XANTHIAS Rathbun.

Xanthodes Dana, Proc. Acad. Nat. Sci. Phila., vi, 75, 1852 (Name preoccupied).

Xanthias Rathbun, Proc. Biol. Soc. Washington, xi, 165, 1897 (Type—*Xanthias granoso-manus* (Dana)).

Xanthias taylori (Stimpson).

Plate XIII, fig. 40.

Xanthodes taylori Stimpson, Ann. Lyc. Nat. Hist. N. Y., vii, 208, pl. 3, fig. 3, 1859.

Xanthias taylori Holmes, Occas. Papers Calif. Acad. Sci., vii, 65, 1900, and synonymy.
—Rathbun, H. A. E., x, 185, 1904.

Quite common and represented in the collection by numerous specimens. Color in life a uniform dark red, lighter below, fingers black. In all the specimens there is a tendency towards fusion of the tubercles on the carpus of the cheliped so that a ridge is formed along the distal end of the joint, while in some specimens from San Diego these tubercles are distinct and more prominent.

Family PINNOTHERIDÆ.

The material in this family is not so extensive or satisfactory as that in the case of the other families here treated, and for that reason no extended treatment is attempted. The following key to genera is in part adapted from Miss Rathbun (Am. Nat., vol. xxxiv, p. 588). No specimens of either *Scleroplax* or *Cryptophrys* were available for comparison; the key moreover is not intended to apply to other than coast forms.

KEY TO THE GENERA OF PINNOTHERIDÆ FOUND IN MONTEREY BAY.

- a. Ischium of outer maxilliped rudimentary.
 - b. Palp of outer maxilliped with three joints.
 - c. Carapace with longitudinal sulci behind the orbits enclosing the median area (legs slender, dactyls of similar length).
Raphonotus
 - cc. Carapace without longitudinal sulci.
 - d. Legs subequal, dactyls of last pair markedly longer than those of preceding pair; carapace suborbicular.
Pinnotheres
 - dd. Legs subequal or markedly unequal, dactyls of last pair always shorter than those of preceding pair; carapace markedly wider than long.
 - e. Third ambulatory leg markedly longer than others.
Pinnixa
 - ee. Third ambulatory leg not markedly longer than others.
Scleroplax
 - bb. Palp of outer maxilliped with two joints.
Cryptophrys
 - aa. Ischium and merus of outer maxilliped separate or incompletely fused.
(Carapace suborbicular, convex, hard; legs stout.) *Opisthopus*

Genus PINNOTHERES Latreille.

Pinnotheres Latreille, Hist. Nat. Crust., iii, 25, 1802.

Pinnotheres nudus Holmes.

Pinnotheres nudus Holmes, Proc. Calif. Acad. Sci., 2d ser. iv, 563, pl. xx, fig. 1-5, 1895.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 86, 1900.—Rathbun, H. A. E., x, 185, 1904.

A single female is in the University collection probably from Monterey Bay, from which locality this species is alone recorded.



Fig. 1.—*Pinnotheres nudus* Holmes. ♀, x 4, Monterey Bay, Cal.

Genus RAPHONOTUS Rathbun.

Fabia Dana, Proc. Acad. Nat. Sci. Phila., 253, 1851.

Raphonotus Rathbun, Proc. Biol. Soc. Washington, xi, 166, 1897 (Type—*Raphonotus subquadratus* (Dana)).

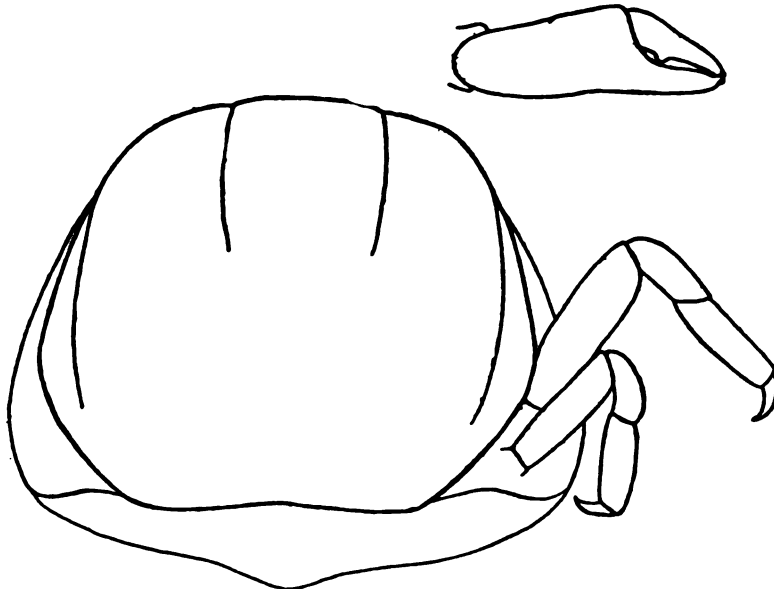


Fig. 2.—*Raphonotus subquadratus* (Dana). ♀, x 3½, Monterey Bay, Cal.

Raphonotus subquadratus (Dana).

Fabia subquadratus Dana, Proc. Acad. Nat. Sci. Phila., 253, 1851.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 87, 1900, and synonymy (part).
Raphonotus subquadratus Rathbun, H. A. E., x, 186, 1904.

Numerous specimens of *Raphonotus* from Monterey Bay agree with Miss Rathbun's description of the portion retained as typical *subquadratus*, in distinction to *R. lowei*, in having a distally widened hand with two rows of hair on the lower margin although they do not all show pubescence of the frontal region. The females are very common in the mantle cavity of the mussel (*Mytilus edulis*)—Miss Rathbun reports it also from folds of *Lucapina crenulata*—but I have seen no males.

Genus PINNIXA White.

Pinnixa White, Ann. Mag. Nat. Hist., xviii, 177, 1846 (Type—*Pinnixa cylindrica* Say).

The genus *Pinnixa* is well represented on the Pacific Coast but the material at hand is scanty. The following key to the species—taken in part from Miss Rathbun and Holmes—is not intended to apply to extralimital forms. I have examined all of the six species.

KEY TO SPECIES OF PINNIXA FOUND IN MONTEREY BAY.

- a. Dactyl of third pair of ambulatory legs straight.
 - b. Carapace about 1½ times as wide as long. *P. faba*
 - bb. Carapace twice or more than twice as wide as long.
 - c. Propodus of third pair of ambulatory legs largest at distal end, markedly wider than base of dactyl; pollux of cheliped not markedly shorter than dactyl and not bent downward. *P. tubicola*
 - cc. Propodus of third pair of ambulatory legs largest near the proximal end, tapering to base of dactyl; pollux of cheliped shorter than dactyl and bent downward at an angle to the palm.
 - d. Carapace about twice as wide as long, areolations well marked. *P. occidentalis*
 - dd. Carapace rather more than twice as wide as long, areolations less prominent. *P. californiensis*

- aa. Dactyl of third pair of ambulatory legs distinctly curved.
 b. Carapace considerably more than twice as wide as long; third ambulatory leg enormously developed, the distal end of the merus not being reached by dactyl of fourth. *P. longipes*
 bb. Carapace twice or less than twice as wide as long; third ambulatory leg not enormously developed, the distal end of the merus being much over-reached by dactyl of fourth.

P. littoralis

(*Pinnixa occidentalis* Rathbun.)

Pinnixa occidentalis Rathbun, Proc. U. S. Nat. Mus., xvi, 248, 1893.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 89, 1900.—Rathbun, H. A. E., x, 187, 1904.

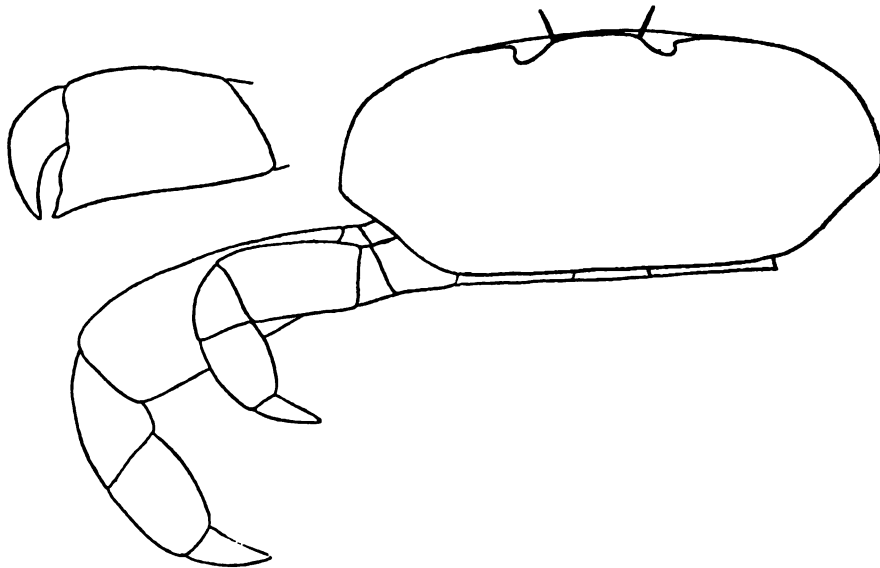


Fig. 3.—*Pinnixa occidentalis* Rathbun. ♂, x 5, Monterey Bay, Cal.

There is in the University collection a bottle containing several specimens of this together with two females of the following species, apparently from Monterey Bay, but as the southern limit of this species as given by Holmes is Humboldt County, I feel some hesitation in adding it to the present list.

Pinnixa californiensis Rathbun.

Pinnixa californiensis Rathbun, Proc. U. S. Nat. Mus., xvi, 249, 1893.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 90, 1900.—Rathbun, H. A. E., x, 187, 1904.

There is beside the two females referred to above, one young female found free on the beach at Pacific Grove which I take to belong to this species as they differ from the preceding in having a smoother and slightly wider carapace. Its range is given as from off Pt. Ano Nuevo to Lower California.

***Pinnixa tubicola* Holmes.**

Pinnixa tubicola Holmes, Proc. Calif. Acad. Sci., 2d ser., iv, 569, pl. xx, figs. 17-18, 1895; Occas. Papers Calif. Acad. Sci., vii, 91, 1900.—Rathbun, H. A. E., x, 187, 1904.

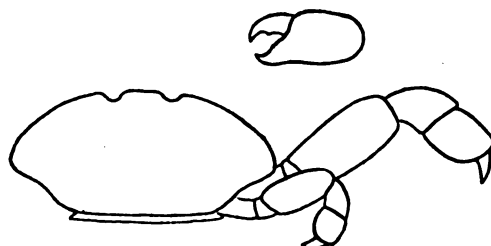


Fig. 4.—*Pinnixa tubicola* Holmes. ♂, x 6, Puget Sound.

A single female dredged from shallow water—10 to 15 fathoms—is in the collection.

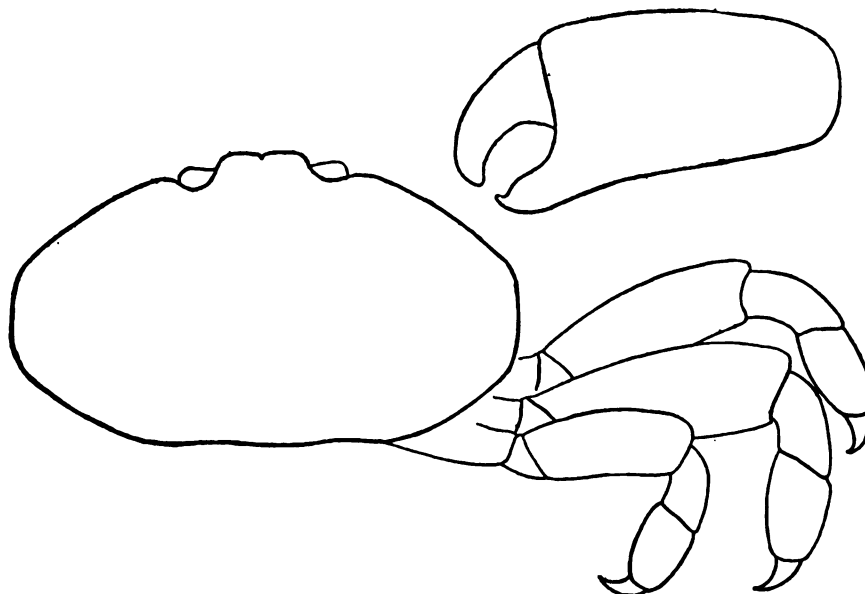


Fig. 5.—*Pinnixa littoralis* Holmes. ♂, x 7, Puget Sound.

***Pinnixa littoralis* Holmes.**

Pinnixa littoralis Holmes, Proc. Calif. Acad. Sci., 2d ser., iv, 571, pl. xx, figs. 14-16, 1895; Occas. Papers Calif. Acad. Sci., vii, 91, 1900.—Rathbun, H. A. E., x, 187, 1904.

"Bodega Bay to San Diego" (Rathbun). I have seen no specimen of this species from Monterey though examples are in the collection from Puget Sound.

***Pinnixa longipes* (Lockington).**

Tubicola longipes Lockington, Proc. Calif. Acad. Sci., vii, 55, 1877.

Pinnixa longipes Holmes, Occas. Papers Calif. Acad. Sci., vii, 92, 1900, and synonymy.—Rathbun, H. A. E., x, 187, 1904.

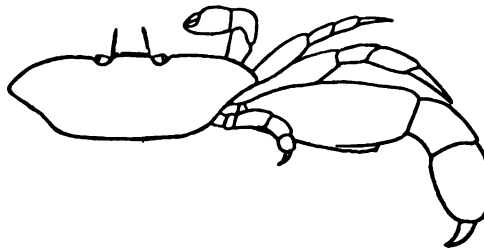


Fig. 6.—*Pinnixa longipes* (Lock.). From Holmes.

"Tomales Bay to San Pedro" (Rathbun). Two young specimens of this species are in the collection.

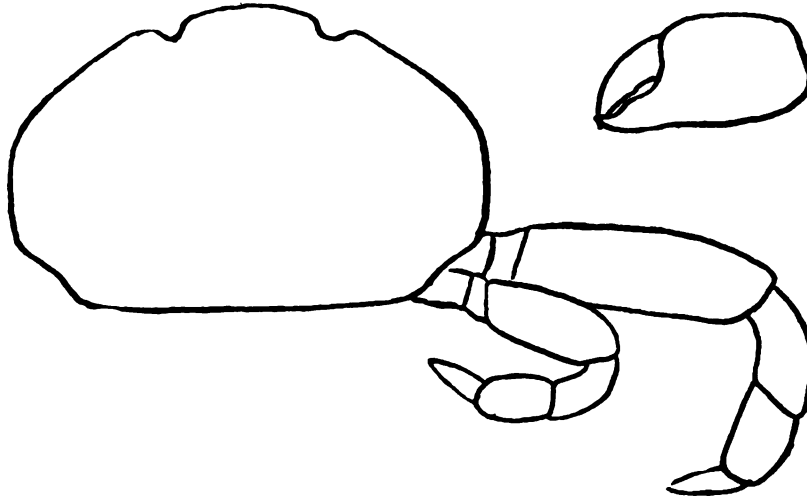


Fig. 7.—*Pinnixa faba* (Dana). ♂, x 12, Monterey Bay, Cal.

Pinnixa faba (Dana).

Pinnotheres faba Dana, Proc. Acad. Nat. Sci. Phila., 248, 1851.

Pinnixa faba Holmes, Occas. Papers Calif. Acad. Sci., vii, 93, 1900, and synonymy.—
Rathbun, H. A. E., x, 188, 1904.

There is one male of this species in the collection obtained free in shallow water—5 fathoms—in Monterey Bay.

Genus SCLEROPLAX Rathbun.

Scleroplax Rathbun, Proc. U. S. Nat. Mus., xvi, 250, 1893 (Type—*Scleroplax granulata* Rathbun).

Scleroplax granulata Rathbun.

Scleroplax granulata Rathbun, Proc. U. S. Nat. Mus., xvi, 251, 1893.

Pinnixa (Scleroplax) granulata Holmes, Occas. Papers Calif. Acad. Sci., vii, 94, 1900.

Scleroplax granulata Rathbun, H. A. E., x, 188, 1904.

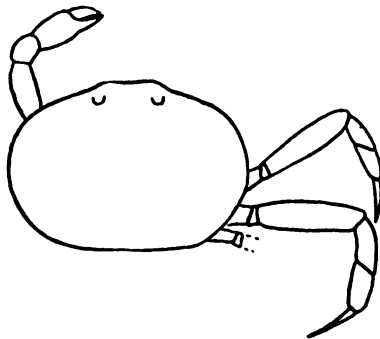


Fig. 8.—*Scleroplax granulata* Rathbun. ♀, x 5, Puget Sound.

“From Bodega Bay, Cal. to Ensenada, Lower Cal.” (Rathbun). I have seen no specimens of this species from Monterey, although several are in the collection from Puget Sound.

Genus CRYPTOPHRYS Rathbun.

Cryptophris Rathbun, Proc. U. S. Nat. Mus., xvi, 250, 1893. (Type—*Cryptophris concharum* Rathbun).

Cryptophrys concharum Rathbun.

Cryptophrys concharum Rathbun, Proc. U. S. Nat. Mus., xvi, 250, 1893.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 96, 1900.—Rathbun, H. A. E., x, 188, 1904.

“From Puget Sound to San Diego, Cal.” (Rathbun). I have a single somewhat damaged specimen which I would place here were it not for the undoubted presence of three joints in the palp of the maxilliped. It is possibly new but on account of its condition I am unwilling to describe it.

Genus OPISTHOPUS Rathbun.

Opisthopus Rathbun, Proc. U. S. Nat. Mus., xvi, 251, 1893. (Type—*Opisthopus transversus* Rathbun).

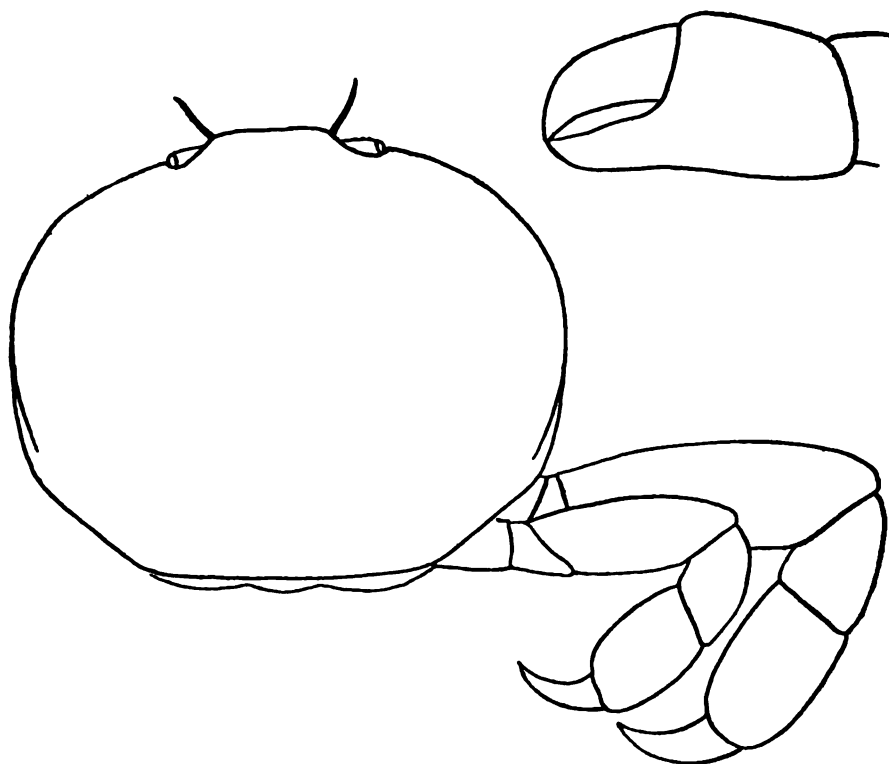


Fig. 9.—*Opisthopus transversus* Rathbun. ♀, x 6, Monterey Bay, Cal.

Opisthopus transversus Rathbun.

Opisthopus transversus Rathbun, Proc. U. S. Nat. Mus., xvi, 252, 1893.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 97, 1900.—Rathbun, H. A. E., x, 188, 1904.

There are numerous specimens of this species in the collection in part from *Stichopus californicus*, a common Holothurian, and *Lucapina crenulata*, the large key-hole limpet. The distinctness of the suture between the ischium and merus of the outer maxilliped varies considerably. All have a more or less clearly defined patch of pubescence along a portion of the antero-lateral margin. The abdomen in the females at hand varies from a width greater than that of the carapace to a size no greater than that of the male. This does not seem wholly due to immaturity as some of the females with narrow abdomens are carrying eggs. A tendency in the hand to approach in shape that of the male accompanies the narrow abdomen.

 Family GRAPSIDÆ.

Key to genera.

- a. Carapace considerably broader than long.
 - b. Carapace transversely striated, external maxillipeds with a wide rhomboidal gape between them. *Pachygrapsus*
 - bb. Carapace smooth, external maxillipeds closely approximated along inner edge. *Hemigrapsus*
- aa. Carapace as long or longer than broad. *Planes*

Genus **PACHYGRAPSUS** Randall.

Pachygrapsus Randall, Jour. Acad. Nat. Sci. Phila., viii, 127, 1839 (Type—*Pachygrapsus crassipes* Randall).

Pachygrapsus crassipes Randall.

Plate XIII, fig. 41.

Pachygrapsus crassipes Randall, Journ. Acad. Nat. Sci. Phila., viii, 126, 1839.—Holmes, Occas. Papers Calif. Acad. Sci., vii, 79, 1900, and synonymy.—Rathbun, H. A. E., x, 189, 1904.

This is perhaps the most common crab on the southern part of the bay where the shores are rocky. It is never found on sandy beaches, but seems to prefer the rocks where it may be found running actively about between or above tides and feeding on cast up fish or other refuse.

General color in life a very dark red with a variable amount of whitish, which is sometimes almost entirely absent and again gives to the whole a light shade. A line of the light color is usually present in front of each of the striæ of the carapace, and spots in the intestinal and cardiac regions. The ambulatory legs are similar in color to the carapace; the chelipeds are generally tan colored veined with red. The thin cuticle at the joints is a livid green.

In the series examined no marked variation was noted.

Genus **HEMIGRAPSUS** (Dana).

Hemigrapsus Dana, Proc. Acad. Nat. Sci. Phila., v, 247 and 250, 1851.—Dana, Am. Journ. Sci., (2) xii, 283, 1851 (Type—*Hemigrapsus crassimanus* Dana).

Key to species.

a. Ambulatory legs smooth, hands with red spots, front sinuous.

H. nudus

aa. Ambulatory legs hairy, hands without spots, front lobed.

H. oregonensis

Hemigrapsus nudus (Dana).

Plate XIV, fig. 42.

Pseudograpsus nudus Dana, Proc. Acad. Nat. Sci. Phila., 249, 1851.

Brachynotus nudus Holmes, Occas. Papers Calif. Acad. Sci., vii, 81, 1900.

Hemigrapsus nudus Rathbun, H. A. E., x, 189, 1904.

A very common crab found on rocky shores with *Pachygrapsus crassipes*. Color in life a very dark purple marked with more or less white or creamish. The chief of these markings occur in the H-shaped depression in the center of the carapace and in the pits lying anterior to it. Ambulatory legs similar to carapace; chelipeds lighter, marked with numerous small spots of darker red. Under parts whitish. Color in alcohol similar, fading only after a considerable time. The color of adults is very uniform, young somewhat more variable.

Hemigrapsus oregonensis (Dana).

Plate XIV, fig. 43.

Pseudograpsus oregonensis Dana, Proc. Acad. Nat. Sci. Phila., 248, 1851.*Brachynotus oregonensis* Holmes, Occas. Papers Calif. Acad. Sci., vii, 82, 1900.*Hemigrapsus oregonensis* Rathbun, H. A. E., x, 189, 1904, and synonymy.

This species is scarce on the southern side of Monterey Bay seeming, as noted by Holmes, to prefer mud flats, where, as in San Francisco Bay, they exist in almost incredible numbers. It is considerably smaller than *nudus*.

Color in life a light grey marked with minute blackish or dark blue spots which are more numerous in some regions than in others. Legs lighter, marked with similar spots; hands of chelipeds whitish, without spots.

Genus **PLANES** Bowdich.

Planes Bowdich, Excursions in Madeira and Porto Santo, pp. xi and 15, pl. xii, figs. 2a, 2b, 1825.

(Planes minutus (Linnaeus).)

Plate XIV, fig. 44.

Cancer minutus Linnaeus, Syst. Nat. Edit., xii, 1048, 1766.*Nautilograpsus minutus* Kingsley, Proc. Acad. Nat. Sci. Phila., 202, 1880.*Planes minutus* Rathbun, H. A. E., x, 189, 1904.

This widely distributed pelagic species has been reported from off the coast of California, and though I know of no record from Monterey Bay, it has been included for completeness.

BIBLIOGRAPHY.

No extensive citation of literature has seemed necessary in view of the small number of papers appearing since the full bibliography given by Holmes. For this reason the synonymy of each species has been limited usually to the original description, a citation of Holmes and reference to such subsequent papers of importance as have been met with.

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——— The Brachyura and Macrura of Porto Rico: Bulletin U. S. Fish Commission for 1900, vol. xx, part 2, p. 1, 1902.

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——— The Brachyura and Macrura of the Hawaiian Islands: Bulletin U. S. Fish Commission for 1903, part 3, p. 827, 1906.

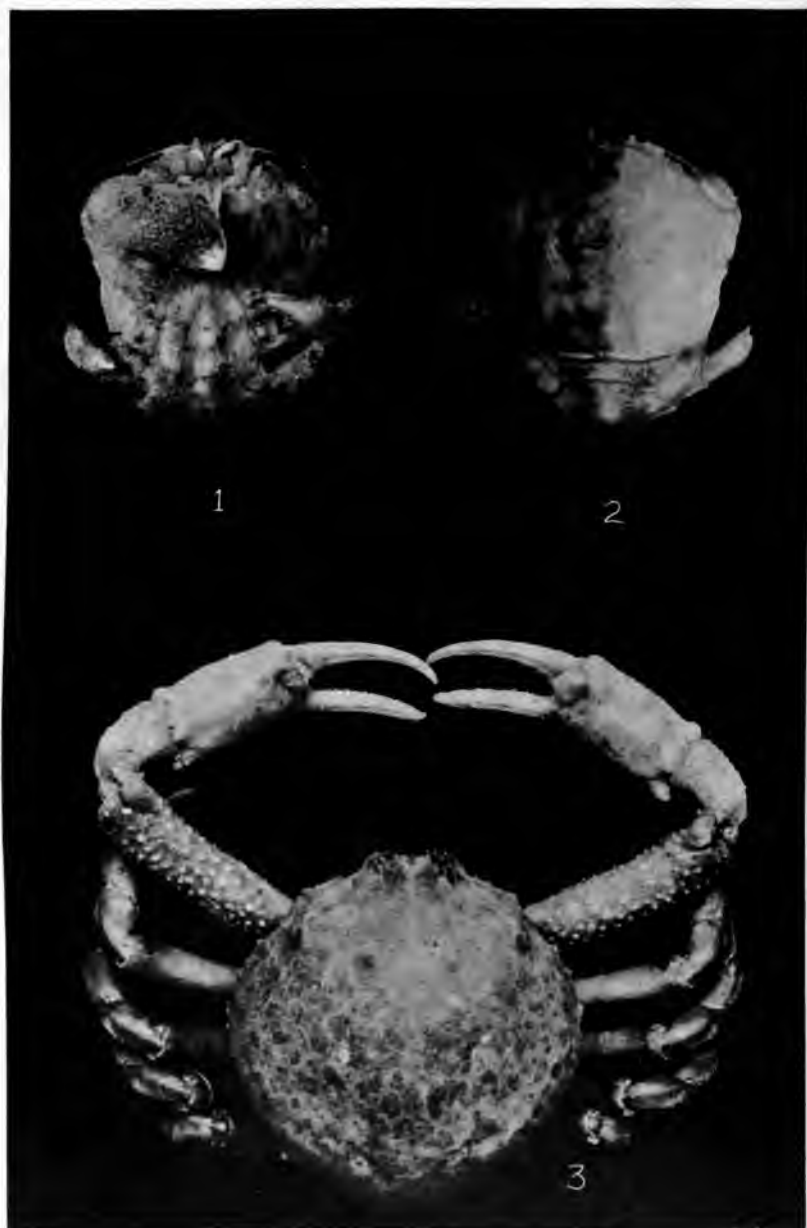
STIMPSON, WILLIAM—Report on the Crustacea (Brachyura and Anomura) Collected by the North Pacific Exploring Expedition, 1853-1856: Smithsonian Miscellaneous Collection, vol. xlv, 1907.

EXPLANATION OF PLATES

All of the plates are from photographs taken by the author of specimens in the Leland Stanford Junior University invertebrate museum. As far as possible the figures are natural size and from specimens obtained in Monterey Bay; the legend of the individual plates will serve to distinguish exceptions to this general statement.

PLATE I.

- Fig. 1. *Dromidia segnipes* new species.
♀, cotype ventral view, x 2. Monterey Bay, Cal.
- Fig. 2. *Dromidia segnipes* new species.
Same specimen, dorsal view. The pubescence has been removed
from the right half of the carapace to show the lateral teeth.
- Fig. 3. *Randallia ornata* (Randall).
♂, nat. size. Monterey Bay, Cal.



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PLATE II.

- Fig. 4. *Heterocrypta occidentalis* (Dana).
♀, nat. size. Monterey Bay, Cal.
- Fig. 5. *Heterocrypta occidentalis* (Dana).
♂, nat. size. Monterey Bay, Cal.
- Fig. 6. *Podochela hemphillii* (Lockington).
♂, x 2. Monterey Bay, Cal.



PLATE III.

- Fig. 7. *Erileptus spinosus* Rathbun.
♂, x 3. Catalina Island, Cal.
- Fig. 8. *Dasygyius tuberculatus* (Lockington).
♂, x 2. Monterey Bay, Cal.
- Fig. 9. *Epialtus productus* Randall.
♀, nat. size. Monterey Bay, Cal.











LELAND STANFORD JUNIOR UNIVERSITY PUBLICATIONS
UNIVERSITY SERIES

No. 5

Osteology
of certain
Scombroid Fishes

BY

EDWIN CHAPIN STARKS

Assistant Professor of Zoology

WITH TWO PLATES AND ONE TEXT FIGURE

(Published May 15, 1911)

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1911



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PLATE II.

- Fig. 4. *Heterocrypta occidentalis* (Dana).
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- Fig. 6. *Podochela hemphillii* (Lockington).
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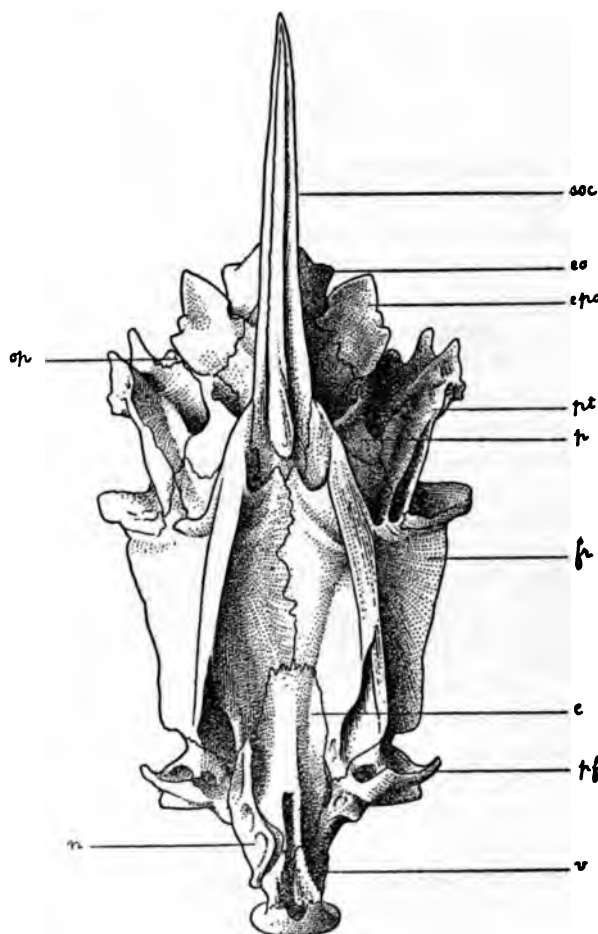
RELATIONSHIP TO THE SCOMBROID FISHES.

That *Leiognathus* belongs with the scombroid fishes there can be little doubt. Its external characters and general appearance, which must be considered, point to such a relationship—to the extent, in fact, that it has often been considered as a member of the family Carangidæ. On the other hand it does not resemble in any way the percoid fishes.

It is not, however, a member of the family Carangidæ, nor is it probably very closely related to it. The gill-membranes are connected with the isthmus in *Leiognathus*. In the family Carangidæ they are free from the isthmus. The suborbital chain is incomplete. In the Carangidæ it is complete. The supraoccipital crest does not extend forward. In the Carangidæ it is carried forward by the frontals for the entire length of the cranium. The alisphenoids are in contact. In the Carangidæ they are separate. *Leiognathus* differs further from the members of the Carangidæ in the peculiar attachment of the hyoid arch to the lateral head bones; in the pelvic arch being deep, and in the very protractile premaxillaries.

Where its relationship lies among the scombroid fishes is more difficult to say. It is probably an abbarrent family like so many others in that relationship. The character of its supraoccipital crest, and its deep pelvic girdle may indicate a connection with the scombroid stem near place where the Chætodontoid fishes branched off.

THE OSTEOLOGY OF LEIOGNATHUS FASCIATUS IN DETAIL.



SUPERIOR VIEW OF CRANIUM OF LEIOGNATHUS FASCIATUS.

Drawn by C. L. STARKS.

<i>e</i> , ethmoid.	<i>fr</i> , frontal.	<i>p</i> , parietal.	<i>soc</i> , supraoccipital.
<i>eo</i> , exoccipital.	<i>n</i> , nasal.	<i>pf</i> , prefrontal.	<i>v</i> , vomer.
<i>epo</i> , epiotic.	<i>op</i> , opisthotic.	<i>pt</i> , pterygoid.	

On each frontal, beginning at the anterior outer edge just behind the prefrontal, is a high, thick ridge which converges backwards with its fellow of the opposite side, and is continuous with the lateral ridge

of the supraoccipital crest. These and the median supraoccipital ridge are finely sculptured on their upper edges, and in the undissected specimen are externally visible, being covered only with very thin skin. Between the frontal ridges there is a broad median area depressed below the level of the supraorbital region on the outer side of the frontal ridges. From the sphenotic a sharp ridge curves upward to the posterior end of the great frontal ridge, joining it near its union with the lateral ridge of the supraoccipital crest. In the base of the lower end of this ridge is the opening of a sensory tunnel, which curving upward and backward pierces the great frontal ridge, and opens at the posterior end of the frontal near the supraoccipital. This sensory tunnel is in continuation with the suborbital and pterotic tunnels, and also with the frontal tunnel, which runs forward traversing longitudinally the great frontal ridge and thence the nasal.

The supraoccipital extends back in a high triangular crest without either extending forward over the frontals, or being in continuation with a median frontal ridge. Following its entire upper contour on each side is a lateral ridge, which is in continuation with the high ridge on each frontal as described above. Posteriorly the supraoccipital extends down over the exoccipital suture, but it does not reach to the foramen magnum.

The exoccipitals meet both above and below the foramen magnum, and their vertebral articular fascets are nearly in contact above the basioccipital. Each bears three foramina more or less in a horizontal line. The middle one, the vagus foramen, has two smaller foramina close beside it, and the anterior one, the glossopharyngus foramen, is only partially contained by the exoccipital, being between that bone and the prootic. The posterior one, the foramen of the occipital nerve, is situated on the ridge that runs forward from the exoccipital condyle to the pterotic crest.

The whole lower posterior part of the basioccipital is occupied by a very large opening to the myodome, filling the width of the bone and leaving its side walls thin. From the upper posterior edge of the basioccipital is a sharp ridge running downward and forward to its lower edge just in front of the posterior opening to the myodome. Between this and the basioccipital condyle are some pits ending blindly, but resembling neural foramina.

The parasphenoid bears a thin median keel below, behind which is a saddle-shaped notch where on each side the first toothless pharyngeal lies. Just back of this is a swollen knob for the support of the other superior pharyngeals, and still farther back, extending under the knob,

is a deep conical cavity with its apex pointed forward, just as in the genus *Gnathanodon* and in several members of the family Scombridae, only the myodome does not open into its side, as it does in the Scombridae. The parasphenoid extends a little behind the front of the posterior opening to the myodome in a little sliver of bone on each side, but it does not reach nearly to the basioccipital condyle. A broad wing is developed upwards along the prootic on each side of the myodome and is strengthened by a lateral ridge continuous with a sharp thin ridge on the prootic and the outstanding wing of the sphenotic. As the prootics and the lower edges of the basioccipital end abruptly against the parasphenoid, without curving inward at all toward each other, the parasphenoid forms the entire lower floor of the myodome.

Through the lateral wing of the prootic is a rather long tunnel—the trigemino-facialis recess, running from the middle of the preorbital surface of the bone forward, and opening on the orbital surface. A foramen opens into this recess at about its middle on the postorbital surface just below the articular cup of the hyomandibular.

The alisphenoids meet and divide the anterior opening of the brain case into two parts—a lower round part, and an upper, much larger, triangular part.

Bordering the posterior half of the lower opening is the basisphenoid. It is connected with the prootic roof of the myodome for its full width without an opening between. It sends down a long process to the parasphenoid.

The sphenotic stands outward in a very prominent lateral wing behind the eye, and is continuous with the frontal supraorbital border. To its outer edge is attached one of the suborbital sensory tube bones, which reaches upward to the frontal.

The opisthotic is almost wholly on the inferior surface of the cranium, though a portion of its thickened posterior end is visible from above. It covers the pterotic-exoccipital suture, and no part of it is interposed between the pterotic and exoccipital. The broad lower limb of the posttemporal is firmly attached to it without the intervention of a ligament.

The parietals are widely separated by both the supraoccipital and the posterior points of the frontal which project backwards. They are situated just above and anterior to the epiotics. Each is in outline an irregularly round bone, and is traversed by a sharp wing running from just behind its middle upward to where the frontal joins the supraoccipital ridge.

PLATE IV.

- Fig. 10. *Pugettia gracilis* Dana.
♂, nat. size. Sitka, Alaska.
- Fig. 11. *Pugettia richii* Dana.
♂, nat. size. "West coast North America"
(U. S. Nat. Museum specimen).
- Fig. 12. *Mimulus foliatus* Stimpson.
♂, nat. size. Monterey Bay, Cal.
- Fig. 13. *Mimulus foliatus* Stimpson.
♀, nat. size. Monterey Bay, Cal.



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PLATE V.

Fig. 14. *Loxorhynchus grandis* Stimpson.

♂, x $\frac{1}{3}$. Monterey Bay, Cal.

Fig. 15. *Loxorhynchus crispatus* Stimpson.

♂, x $\frac{1}{2}$. Monterey Bay, Cal.



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PLATE VI.

- Fig. 16. *Chorilia longipes* Dana.
♂, nat. size. Albatross station No. 4351,
Cal. coast off Point Loma.
- Fig. 17. *Scyra acutifrons* Dana.
♂, nat. size. Monterey Bay, Cal.



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The three families here considered differ but little from the family *Scombridae*. The eye has no bony sclerotic case, there are no separate bony basosteæ, and the caudal rays are not deeply divided at the base to receive the hypural plate.

These three families have the following characters in common: prefrontals meeting at the median line, with the ethmoid appearing nowhere between them posteriorly; alisphenoids separated from each other; supraoccipital extending over the epiotic suture, but not separating epiotics as viewed from within the cranium; myodome and basi-sphenoid present: the latter with a descending process; eye without a bony sclerotic case; ascending processes of premaxillaries not developed; supplementary maxillary present; teeth in alveoli; coracoid suture ending at middle of third actinost from top; head of hyomandibular divided into two parts; symplectic joined to metapterygoid by a dentate suture; three pairs of tooth-bearing pharyngeals present; the anterior basibranchial remote from the first hypobranchial; anterior ribs and epipleurals attached to vertebral centra; caudal rays, when present, not deeply divided.

The principal characters that differentiate these families is shown in the following synopsis:

GEMPYLIDÆ (*Promethichthys*)

The pterotic and temporal crests coterminous against an oblique ridge from the supraoccipital; myodome opening posteriorly through a rather broad foramen; opisthotic on lower surface of cranium not separating the exoccipital from the pterotic; suborbital ring complete and with a sensory tube; pelvic bones attached between clavicles; no parapophyses present, but hæmal arches developed behind middle of abdominal portion of vertebral column; no sharp ridge along the side of vertebræ; ribs anteriorly in pits on centra, posteriorly at tips of abdominal hæmal spines with their bases in contact as in the family *Scombridae*; body incased in two series of intermuscular rays, the upper series composed of epipleurals.

LEPIDOPIDÆ (*Lepidopus*)

The temporal crest ending as in *Promethichthys*, but the pterotic crest ending against middle of temporal crest; myodome opening posteriorly through a very small pore; opisthotic partly on superior surface of cranium, and separating exoccipital from pterotic for a con-

siderable distance; suborbital ring not complete, and without a sensory tube; pelvic bones represented by a pair of long, simple rays lying free just beneath the skin remote from the shoulder girdle; no abdominal hæmal arches present; small, slender parapophyses present on last two vertebræ; a sharp keel running along side of vertebræ for nearly whole length of vertebral column; body not incased in rays of bone, and only four or five epipleurals present anteriorly.

TRICHIURIDAE (*Trichiurus*)

Skeleton differing from *Lepidopus* in having no pelvic bones (not represented in all *Lepidopidæ*); in having the tail taper to a point which is without hypural bones or caudal fin; and in having the weak anal reduced to short, stiff spines.

In the following descriptions the osteology is given in detail.

PROMETHICETHYS.

A specimen of *P. prometheus* from the Canary Islands, 17 inches in length.

The cranium is elongate and the preorbital portion is somewhat produced. The crests and ridges on the superior surface form a complicated pattern, but in general resembling those of *Scomber*, having an oblique ridge from the supraoccipital against which the temporal and pterotic crests stop. This ridge is forked in front of the temporal crest, and the inner branch runs forward to the ethmoid, while the outer reaches the edge of the cranium above the front of the eye. The myodome opens through a round foramen posteriorly. The occipital region is not produced as in *Scomber*.

The exoccipitals meet broadly over the basioccipital, and have large condyles overhanging the latter. The supraoccipital extending down over the suture between the epiotics and the upper part of the exoccipitals appears from the exterior to separate them, though both the epiotics and exoccipitals meet for their full length within the cranium as in the *Scombridæ*.

The supraoccipital crest is but little developed. It is considerably behind the eye and not very far anterior to the occipital condyle. It is not formed at all by the frontals anteriorly, and scarcely rises above the level of the temporal crests. It has no sharp apex directed upward as in *Lepidopus*.

The basisphenoid is present and has a descending process to the parasphenoid. The alisphenoids are widely separated by the anterior opening to the brain cavity. The prefrontal is elongate and meets its fellow of the opposite side at the median line in front of the orbital cavity. It has the usual lateral wing which is pierced by the olfactory nerve and supports the posterior end of the palatine below. In front of the prefrontal a lateral protuberance is formed by the vomer and ethmoid and extends up nearly to the frontal. The vomer is obliquely truncate on each side for the articulation of the maxillary. The opisthotic is on the lower surface of the cranium covering the exoccipital-pterotic suture, and scarcely showing on the superior surface. To its posterior edge the lower limb of the post-temporal is attached.

The nasals are rather wide and are attached to the front of the frontals and ethmoid. They are produced anteriorly in front of the ethmoid over the maxillary. The preorbital is long and carries a sensory tube in continuation with that of the suborbitals. The suborbitals are little more than a chain of small bony tubes, but they form a complete suborbital ring. There is no suborbital shelf, and the eye is not incased in a bony sclerotic cup.

The premaxillary bears only a slight suggestion of an ascending process. The maxillary carries a long, narrow, supplementary maxillary along its upper edge. The anterior inner end of the maxillary has a conspicuous fascet for articulation with the vomer. The teeth on the side of the premaxillary are set in alveoli, but the long lance-like canines, forming a short inner row in front, though developed from cavities are of a different character, as the cavities behind them become filled with "bone of attachment" as the teeth are pushed out.

The head of the hyomandibular is divided into two parts, though a little less completely than in the Scombridæ. The opercular elements are not so smoothly united to each other. The upper part of the symplectic is united to the metapterygoid by a dentate suture as in *Sarda* and *Thunnus*. The palatine is armed with a single row of small sharp teeth, and anteriorly the usual process extends over the maxillary. The articular entirely fills the notch in the dentary; a small angular is present. The teeth at the side of the dentary resemble those of the premaxillary, but one or two teeth at the front are apparently of the character of the inner premaxillary row.

The posttemporal is a slender, widely forked bone. Its upper limb is rather solidly attached to the epiotic, and slightly overlaps the parietal, but it does not impinge on the supraoccipital as in some of

the Scombridæ. Its lower fork is attached to the posterior edge of the opisthotic. A well developed supraclavicle is present. Above the pectoral the clavicle is bent at a considerable angle, allowing the body of the shoulder girdle to extend forward even more horizontally than in the Scombridæ. The hypocoracoid foramen is large and at the center of the bone. The hypocoracoid differs from that of the Scombridæ in reaching downward to the end of the clavicle. The actinosts are a little longer and more slender than in *Scomber*, but arranged the same in relation to the coracoid elements, the third from the top being opposite the coracoid suture. There is no wing from the clavicle above the pectoral fin to support the postclavicle. The superior element of the postclavicle is very short and firmly attached to the clavicle; the inferior element is long, slender and slightly expanded below, the two portions appearing as a single piece.

The pelvic girdle is very long and slender, extending forward to between the clavicles and attached in the way usual to thoracic ventrals.

As in the Scombridæ, there are three basibranchials; the anterior one remote from the hypobranchial of the first arch. Four pairs of superior pharyngeals are present; the first toothless; the second long and narrow and lying beside the third; the third the largest; and the fourth in line behind it, and lying so close that the third and fourth form an almost continuous tooth patch, though they are not so closely connected as in the Scombridæ.

The glossohyal and urohyal are both present; the latter without lateral ridges. A pair of very large hypohyals are present on each side; a long ray of bone from the ceratohyal extends under them to support the anterior branchiostegal ray. Four branchiostegal rays are upon the ceratohyal and three upon the epihyal.

There are 20 abdominal vertebræ and 13 caudal, or a total of 34 with the hypural. There are no parapophyses, but on the 11th vertebra there is a small, round, hæmal arch, formed by connected parapophyses, as in the Scombridæ. It is without a spine, is inclined forward, and is longitudinally flattened. Posteriorly the abdominal hæmal arches gradually develop a spine and incline backward. The ribs are set in sockets anteriorly low on the centra of the vertebræ, and posteriorly are carried at the tips of the hæmal arches, each pair with their bases in contact as in the Scombridæ. Each rib or hæmal arch is placed almost directly at the middle of the vertebra. The neural arches are more posterior, but still at some distance from the ends of the vertebræ.

Two series of long, slender bones lie just beneath the skin and incase the body, one series above and one below the middle of the side. The upper series is composed of the epipleurals, which curve outward to the skin and then upward nearly to the dorsal. The lower series is an extra intermuscular ossification, and is perhaps not present in the young, as is the case with a similar ossification in the genus *Chanos*. The first two vertebræ bear epipleurals only. On the third vertebra and some of the succeeding ones the epipleurals and ribs join the vertebræ together, with their bases connected, but a short distance back the epipleurals lose all connection with either ribs or vertebræ and lie loose in the intermuscular connective tissue. The last two or three vertebræ are as in *Scomber*, not abruptly shortened as in most of the Scombridæ. There is no trace of a lateral caudal keel. The hypural bears a large urostyle.

The upper ends of the interneurals of the spinous dorsal are laterally expanded, and probably represent the anchylosed basecosts. No separate bony basecosts are present in any of the fins. The bases of the caudal rays are not deeply divided, nor are the rays widely divergent as in most of the Scombridæ.

A skiograph of *Epinnula magistralis* from a specimen in the U. S. National Museum shows the number of vertebræ to be 15 + 17 (counting the hypural); the ribs are borne at the tips of the abdominal hæmal spines; the body is not incased in a series of intermuscular rays, as in *Promethichthys*, and the ventral fins are attached to slender pelvic bones which extend between the clavicles.

LEPIDOPUS.

A specimen of *L. caudatus* from the Canary Islands, measuring 3 feet in length.

In this form the supraoccipital crest is far anterior to that of *Promethichthys*. As viewed from the side of the cranium it rises as a stout triangular process far above the rest of the skull, with its sharp apex directed upward. It is over the posterior part of the orbital cavity, or nearly a fourth of the distance from the occipital condyle to the tip of the vomer. The frontals form the anterior part of it. The ridges, which in *Promethichthys* are low, and run from the front of the supraoccipital obliquely to intercept the temporal crest in *Lepidopus*, are high, sharp ridges, starting at the apex of the supraoccipital crest and running more directly forward. Deep between them is a small median ridge representing the front part of the supraoccipital crest.

Instead of the pterotic and temporal crests being coterminous anteriorly, the latter ends against the middle of the former, which continues alone to the ridges from the supraoccipital. The epiotics meet very broadly behind the supraoccipital, but a thin sheet of bone from the supraoccipital extends over the median suture between them and reaches down to the exoccipitals. The sheet of bone is so thin and transparent that it is difficult to see it, and the outline of the epiotics is clearly to be seen through it. The ethmoid is not at all posterior to the front of the vomer. The lateral process of the parasphenoid ends as a free point nearly reaching the alisphenoid. The opisthotic separates the exoccipital from the pterotic to a considerable extent, and the lower limb of the posttemporal is attached to its superior surface a little before its posterior edge. The myodome is nearly closed posteriorly. With these exceptions the cranium is very similar to that of *Promethichthys*.

The suborbital ring is incomplete posteriorly, and there is a suborbital shelf loosely attached to the bones anterior to it. The preorbital is large and traversed by a sensory tube, which is not in continuation with the suborbitals.

The maxillary and teeth are essentially as in *Promethichthys*. The middle portion of the maxillary projects behind in a thin wing, and the supplementary maxillary is not very large.

The head of the hyomandibular is widely divided into two portions. The opercle and subopercle are made up posteriorly of radiating rays of bone, which stand apart like bristles when the tissue connecting them is removed. The symplectic is suturally connected with the metapterygoid, and all of the lateral head bones are almost identical with those of *Promethichthys*.

As the cranium extends backward below the upper limb of the posttemporal farther than in *Promethichthys*, the lower posttemporal limb is not in consequence so long. A tube bearing supratemporal is present.

The portion of the clavicle above the pectoral fin is nearly as long as the portion below, and is turned at a right angle to the latter. The hypocoracoid is thin and much produced backwards. The actinosts are shorter than in *Promethichthys*, but arranged the same in reference to the coracoid elements, and the arrangement of the postclavicle is the same.

The pelvic bones are long, simple rays, lying just beneath the skin, remote from the shoulder girdle. The flattened or scale-like ventral

spines are attached at about the anterior third of the length of the pelvic bones.*

The branchial and hyoid elements are almost identical with those of *Promethichthys*.

There are 41 abdominal vertebræ, and in the specimen at hand 62 caudal, besides a few (probably not exceeding 5) that are missing at the end of the tail.

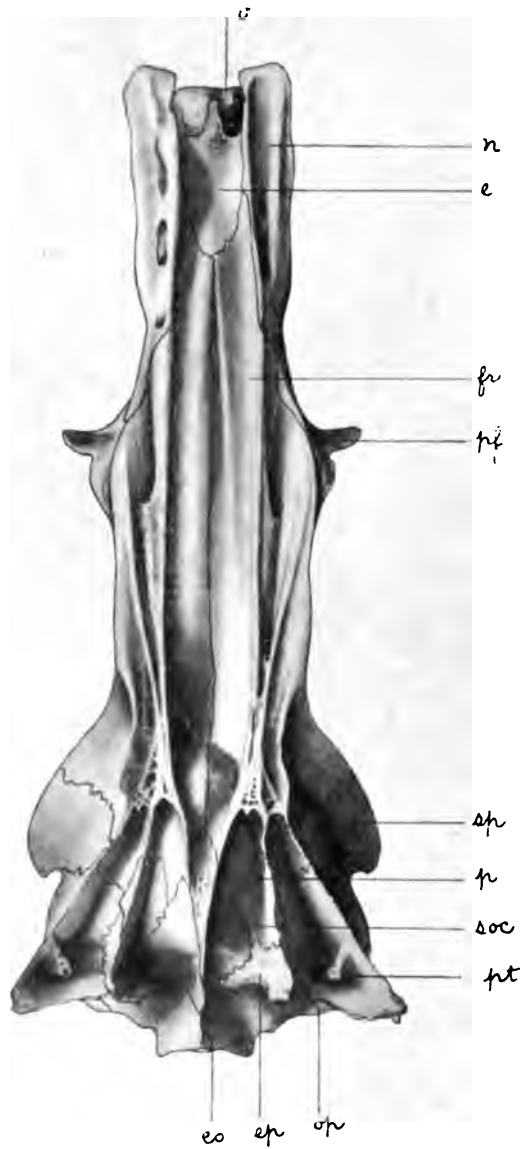
Lepidopus differs from *Promethichthys* in having no abdominal hæmal arches. The last two abdominal vertebræ bear small, slender parapophyses, but the ribs are still attached to the vertebral centra at the base of them, though they are also attached to the full length of the parapophyses at the side. The abdominal hæmal arches and spines in *Promethichthys* are not differentiated from those of the caudal region, but in *Lepidopus* the change from the small parapophyses of the last abdominal vertebræ to the large hæmal arch and spine of the first caudal vertebra is very abrupt. The ribs are set in very deep pits low on the vertebral centra, and, as in *Promethichthys*, each rib or hæmal spine occupies a position at about the middle of the length of its vertebra. There is a sharp, low, lateral ridge running the length of the vertebral column. Along the caudal region it occupies the middle of the sides of the vertebræ, and is a little elevated at each end of each vertebra. On the abdominal region it is ventral in position, and forms a sharp lower edge, which bears the sockets for the ribs.

The first two vertebræ bear epipleurals only. There are only three other epipleurals attached to the vertebral centra just above the base of the ribs. There are no long intermuscular bones incasing the body, as in *Promethichthys*. The hypural is small, but in no way remarkable; the caudal rays are not deeply divided. The interneurals are T-shaped, with the horizontal limb connecting them, and forming the outline of the back. They are only slightly expanded laterally just beneath the skin. No ossified, separate baseosteos are present. The fourth and fifth interneurals bear large bean-shaped swellings near the upper end, each nearly as large as a vertebra.

*The abdominal ventrals might indicate a direct descent from more primitive forms with similar ventrals, did not *Promethichthys* (with thoracic ventrals) so obviously stand between. This condition in *Lepidopus* probably shows an independent degeneration or modification. As the body has become elongate, and the ventrals functionless, the latter have lost their connection with the shoulder girdle and have moved backwards. Since the above was written a paper by Mr. C. Tate Regan (Ann. and Mag. Nat. Hist. (8) Vol. III. 1909) has been received in which he has come to the same conclusion: "This condition may be regarded as secondary and due to the degeneration of the fins."

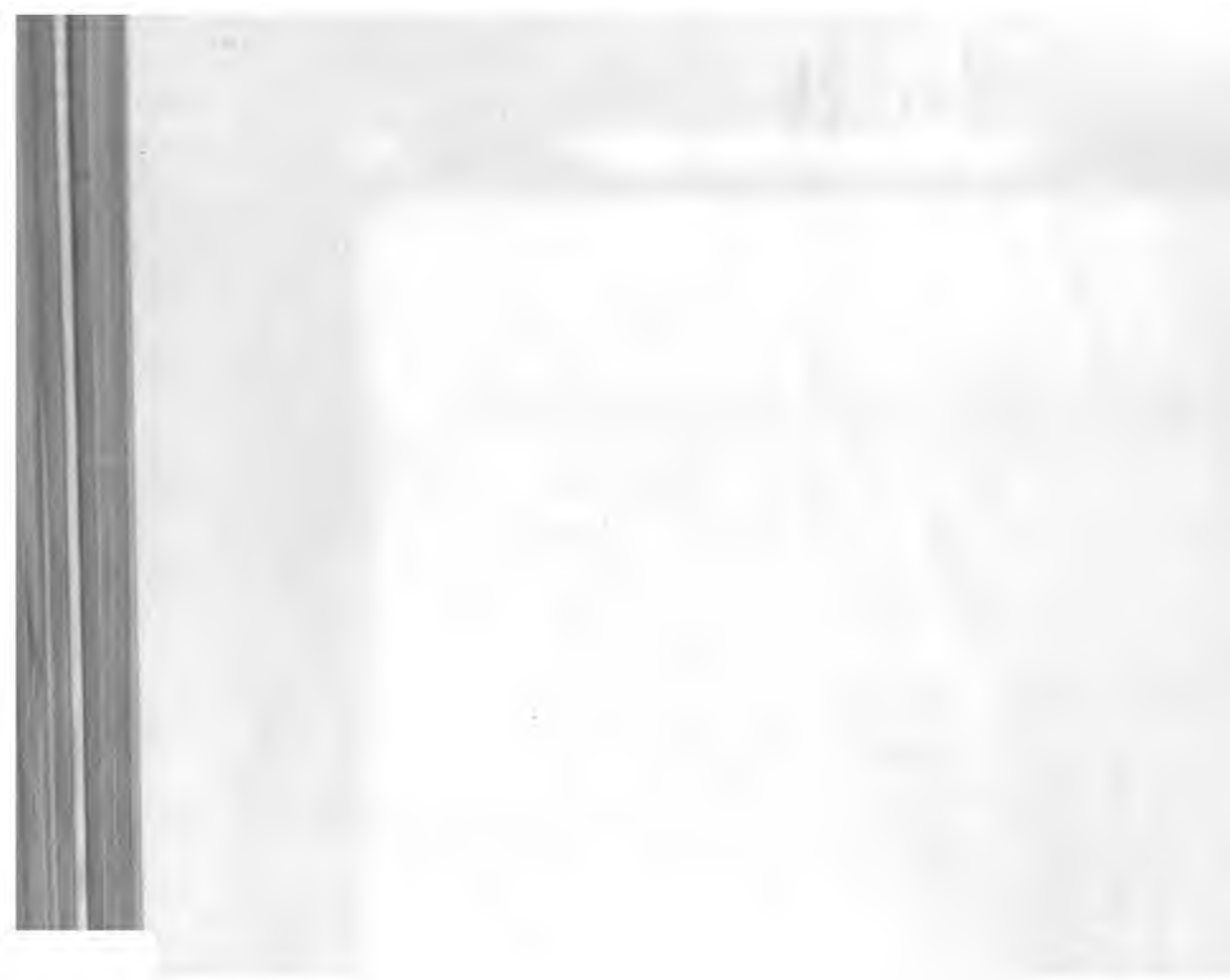
bones are entirely absent. The hyoid and branchial arches differ in no way from those of *Lepidopus*.

There are 39 abnormal vertebræ, and 100 caudal vertebræ may be counted to where the tail tapers to so fine a point as to make counting difficult. The vertebræ are much shorter than in *Lepidopus*, and in consequence the neural and interneural bones are at shorter intervals and with shorter arms between the fin rays. The lateral ridge along the vertebral column is much higher and sharper, the anal is represented by very small sharp spines, there are no swollen interneurals, and the tail tapers to a point without a hypural bone or caudal fin. Otherwise the vertebral column and fin elements are nearly identical with those of *Lepidopus*.



PROMETHICHTHYS PROMETHEUS.

C. L. STARKS, del.



MUTUAL RELATIONSHIP.

The family Carangidæ is a much more compact group than the Scombridæ. The gaps between the genera are much smaller, and though the osteological characters, like the form of the body, differs much in the extremes of variation, there are no sudden or complete changes. Consequently the genera do not so readily group themselves into subfamilies as do the genera of the Scombridæ. Though the groups here indicated are not very definite, they may show at least relationship.

The subfamily Scombroidinæ contains the genera *Oligoplites* and *Scomberoides*. It may be distinguished by the non-protractile premaxillaries, the presence of many finlets, the broad union of the epiotics within the cranium, the slightly increased number of vertebræ, and the ribs (except the posterior two or three pairs) attached high on the side of the centrum, not even in contact with the parapophyses.

Oligoplites and *Scomberoides* do not resemble each other so closely as might be expected from their close external resemblance. The latter differs from the former in having a supplemental maxillary. In *Scomberoides* the temporal crest reaches far forward to above the prefrontal, while in *Oligoplites* it ends over the posterior part of the eye. In *Scomberoides* the top of the cranium is deeply concave at each side of the supraoccipital crest above the eye, while in *Oligoplites* it is flat. In *Scomberoides* the exoccipital condyles are broadly in contact, while in *Oligoplites* they are separate. *Scomberoides* has a well developed subocular shelf, which in *Oligoplites* is absent.

The Naucratinæ includes *Naucrates*, *Seriola* and *Elagatis* (the vertebral column of the last has not been seen). This group is distinguished by having the first interhæmal unenlarged, the last one or two pairs of parapophyses each united to form a hæmal arch and spine, at the tip of which the ribs are attached with their bases in contact, the first hæmal spine unenlarged and not firmly attached to the first interhæmal, the lateral line not abruptly arched, and the anal not preceded by two free spines. In the other Carangoids the posterior parapophyses are distinct, not united as a single hæmal spine, though a bridge of bone connects their bases.

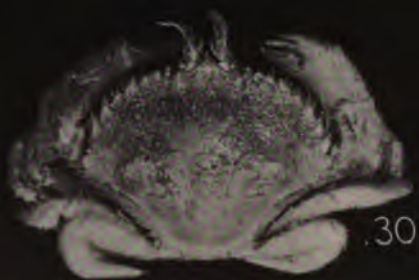
Decapterus in the condition of the posterior parapophyses approaches this character. It shows an alliance to *Elagatis* in the pos-

PLATE X.

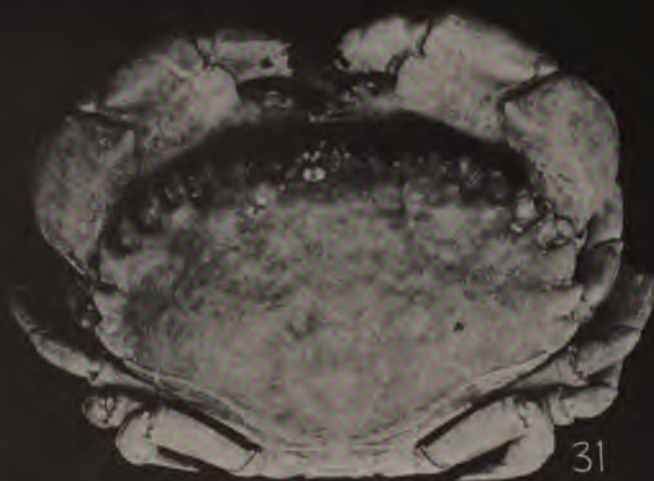
- Fig. 29. *Cancer gibbosulus* (de Haan).
♂, nat. size. Monterey Bay, Cal.
- Fig. 30. *Cancer jordani* Rathbun.
♂, nat. size. Monterey Bay, Cal.
- Fig. 31. *Cancer antennarius* Stimpson.
Adult ♂, x ½. Monterey Bay, Cal.
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Vertebrae in small numbers; the abdominal always 10; the caudal from 14 to 16 (usually the former).

Parapophyses not developed very far anteriorly; the last two or three pairs with a bridge of bone connecting them; but they do not (except in the Naucratinæ) unite in pairs, each pair to form a single hæmal spine.

Epipleurals anteriorly borne by ribs (only so in one genus of Scombridæ).

First interhæmal enlarged (except in the Naucratinæ) and very closely attached to the enlarged first hæmal process.

Caudal rays rather deeply divided, usually not so much so as in the Scombridæ, but more than in the Percoid fishes.

Dorsal spines usually stiff and stout; dorsal and anal finlets sometimes present.

Caudal peduncle slender and the caudal rays divergent.

HYPEROSTOSIS.

Many of the forms of this family have some thickened bones. These are here described away from the main descriptions for better comparison. They are usually dense or ivory-like on the surface, but are more or less cellular inside. Apparently they are a development of age rather than of maturity. That entirely different bones may become thickened in different species of the same genus, or between closely related species, is shown in the two species of *Caranx* here described. It appears further from this material that where the bone thickening occurs at all it occurs consistently in the same bones in individuals of the same species. What individual variation may be expected, or what taxonomic value the character may have, we have not enough material at hand to say. As shown, however, by *Selene* and *Citula*, there may be considerable variation in the size of the thickening, or it may not develop at all in species that normally, or sometimes, have it at a certain age or size. There is no proof with this material that in the latter case, where it has not occurred, it might not have developed with time. The problem should be studied in some locality where a large number of Carangoids of different ages may be examined.

In *Oligoplites mundus*, 18 inches in length, the frontals above the orbital cavity are so thickened that the supraoccipital crest is nearly obliterated. The frontals in this region are nearly $\frac{1}{2}$ inch in thickness. On the lower end of the clavicle is a swollen area $1\frac{1}{2}$ inches

PLATE XI.

- Fig. 32. *Cancer antennarius* Stimpson.
♀, nat. size. Monterey Bay, Cal. The extreme
pubescence here shown is not typical of the
species.
- Fig. 33. *Cancer anthonyi* Rathbun.
♂, x 1/2. San Diego, Cal.
- Fig. 34. *Cancer oregonensis* (Dana).
♀, nat. size. Orca, Prince William Sound,
Alaska.



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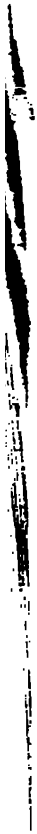


PLATE XII.

- Fig. 35. *Portunus xantusii* (Stimpson).
♂, nat. size. San Diego, Cal.
- Fig. 36. *Cycloxanthops novemdentatus* (Lockington).
♂, nat. size. Monterey Bay, Cal.
- Fig. 37. *Lophopanopeus bellus* (Stimpson).
♂, nat. size. Monterey Bay, Cal.
- Fig. 38. *Lophopanopeus heathii* Rathbun.
♂, nat. size. Monterey Bay, Cal.
- Fig. 39. *Lophopanopeus diegensis* Rathbun.
♂, nat. size. Monterey Bay, Cal.



PLATE 1
CRABS
1891

forming a roof, and the ethmoid forms a septum between it and its opposite fellow, though behind the ethmoid there is a communicating passage, which in the fresh fish was probably filled with cartilage. The olfactory foramen enters this chamber at its outer edge. *Seriola* and *Naucrates* have only a trace of this chamber. It is particularly well developed in *Gnathanodon*, but is lower on the prefrontal, and the frontal forms no part of its roof, though the ethmoid forms a large part of it. It is in this form much deeper than long, and extends downward to the parasphenoid. The olfactory foramen enters the posterior end of it. It is similar to *Gnathanodon*, though scarcely so large, in *Trachurus*, *Trachurops* and *Decapterus*; in *Megalaspis* it is considerably smaller. It is moderately developed in *Citula* and *Alectis*, but the foramen is so far to its outer edge that it can be scarcely said to enter it. In *Chloroscombrus*, *Vomer* and *Selene* it is not well developed, and in *Trachynotus*, *Caranx*, *Oligoplites* and *Scomberoides* it is not present at all.

The vomer bears a keel on its upper surface, which is a continuation of the ethmoid keel. At each side of the keel rests the ascending premaxillary process.

The parasphenoid is sharply keeled under the orbital cavity. At the mouth of the myodome it sends a lateral wing up along the edge of the prootic, but it is confined to that bone, never reaching to the alisphenoid or sphenotic. *Trachynotus* differs from the other genera in having the parasphenoid expanded to two or three times its ordinary width to form a broad, flat table, against which the greatly enlarged superior pharyngeals lie. This expansion is reinforced above by the prootic, which is developed outward to the edges of the parasphenoid, or a little beyond. *Gnathanodon* differs from the others in having a protuberance on the parasphenoid under the prootics, which contains a conical cavity with its apex pointing straight forward. This is doubtless the homolog of a somewhat similar cavity in the Tunninæ division of the Scombridæ, into which the posterior myodome foramen enters. In *Gnathanodon*, however, it is farther forward, remote from the foramen.

Other cranial elements not mentioned do not depart to any notable extent from the majority of spiny-rayed fishes.

The Lateral Head Bones.

The lateral bones of the head do not differ materially from those of the family Scombridæ. The bones of the suspensorium set closely together, and there are usually no openings between them.

The opercular bones do not in general form such broad, smooth areas as in the Scombridæ. There are no preopercular serrations except in the very young, and there is never an open sensory canal along the preopercular ridge. When there is any indication of a sensory system in the bone in this region it is in the form of very fine tubes. *Trachurus* is somewhat of an exception to this in having much larger tubes than in any of the other genera.

The head of the hyomandibular, where it articulates with the cranium, is more or less divided into two parts. In *Gnathanodon* the parts are contiguous, or with only a slight notch between them. In *Elagatis* they are remote from each other. Between these two degrees of separation there are all intermediate conditions, though they are usually at least slightly separated. The hyomandibular is channeled behind to receive the preopercle, and sends back a process to support the opercle. In *Oligoplites* the upper end of the hyomandibular bears on its outer surface a large wing of bone, pointing forward as in *Caranx hippos* (see under suborbitals), but there is no stay from the suborbital ring attached to it. In *Scomberoides* this process is reduced to a small, inconspicuous point.

There is never any opening between the hyomandibular and metapterygoid that frequently appears in Percoid fishes except in *Gnathanodon*, and to a slight extent *Trachurus*. The condition in the former genus is identical with that of *Roccus*. The metapterygoid throws out a broad wing, which extends backward to near the preopercular ridge, leaving a wide, open space behind it. In *Trachurus* the wing is feebly developed, and it fits so closely against the hyomandibular that the open space is scarcely apparent. No trace of it is apparent in any of the others.

The mesopterygoid forms a broad supporting shelf for the orbit.

The symplectic extends for a considerable distance behind the quadrate in a channel.

Usually the pterygoid turns at a right angle and reaches forward towards the prefrontal, as it does in the majority of fishes. The anterior end of the pterygoid, and often a small part of the posterior end of the palatine is attached to the prefrontal. Often a small tubercle of bone is developed on the pterygoid just behind this attachment. But as the cranium becomes flexed downward and the face bones drawn forward, as in some of the deep, compressed forms, the pterygoid is directed nearly straight upward and finally even somewhat backward, while the tubercle of bone becomes a long spur or process extending

behind the prefrontal. *Gadus* and *Chelodactylus* show a marked inclination towards this position. The pterygoid is developed nearly straight upward and the process behind the prefrontal is long. In *Alepis* and *Citella* the pterygoid is bent farther back and the process is longer, while in *Vomer* and *Selache* it is bent very decidedly back, the process is still longer, and serves as the only attachment of the pterygoid to the prefrontal.

The palatine is attached more or less firmly, and with or without a differentiated articular surface, to the front of the prefrontal. The anterior end bears a strong process, which hooks over the maxillary.

The angular is well developed. In *Oligoplites* and *Vomer* the articular completely fills the V-shaped space between the backward extending arms of the dentary. In *Scomberoides* a small space is unfilled above. In *Naucratis* and *Elagatis* a considerable space is unfilled, and in the others the upper arm of the dentary and the upper edge of the articular are only in contact at a small place anteriorly.

In *Oligoplites* the dentary is peculiar in having a free wing of bone on the inside, running forward nearly to the symphysis. This wing is present in nearly all other bony fishes, but it curves downward and becomes absorbed near the middle of the mandible. In *Scomberoides* this free wing does not run far forward, but from below its lower edge a second wing is developed, which folds downward and runs back to the posterior end of the lower limb of the dentary, keeping considerably above the lower edge of the dentary for its full length.

In *Oligoplites* and *Scomberoides* the maxillary and premaxillary elements are long and slender, and rather closely attached to each other. The premaxillary sends no sharp spur behind the maxillary, though a long inner fold of bone clasps the latter rather closely. A supplementary maxillary is not present in *Oligoplites*, but in *Scomberoides* it is developed, though rather small as compared with those of the other Carangoids. In *Trachinotus* the maxillary elements are short and loosely attached to each other; the maxillary spur behind the premaxillary is little developed; and the supplementary maxillary is absent. In all of the other forms the maxillary elements are very wide, particularly the posterior end of the maxillary; rather loosely attached to each other, especially in those forms with long premaxillary processes; they bear upon their upper edges very large supplementary maxillaries, and from the middle of the premaxillary a large triangular spur is sent behind the maxillary.

The ascending processes of the premaxillaries are very short and triangular in *Oligoplites*, *Scomberoides*, *Elagatis* and *Naucratis*. In

Decapterus, *Megalaspis*, *Caranx*, *Trachurus*, *Trachurops* and *Chloroscombrus* they are longer, while in the rest, *Gnathanodon*, *Alectis*, *Citula*, *Vomer* and *Selene*, they are very long.

The nasals are attached to the frontals and ethmoid and project forward. They are never nonprojecting and attached for their full length to the frontal and ethmoid, as in some genera of the family Scombridae. They are close together or wide apart, according to whether the ethmoid is wide or narrow, so their variation in this respect is indicated by the description of the ethmoid. In *Trachurus*, which has the thinnest ethmoid, the nasals are almost in contact at their bases.

The suborbital chain of bones is always complete and carries a sensory tube. In *Caranx hippos* a wide process is sent from the last suborbital that is on the lower level of the eye (apparently the third suborbital) upward and backward across the cheek to the upper end of the hyomandibular, where it is attached to a broad, thin wing of bone, which bends forward to receive it from just in front of the upper end of the preopercle. The upper suborbitals send back a wide, thin plate, which partly covers this stay. In *Caranx chrysos* the stay is only a little developed. It ends in a free point, and there is no process developed from the hyomandibular to meet it. In *Oligoplites* the lower and posterior suborbitals are spread out into thin laminae, which, running backwards, covers a large part of the cheek. The lower edge of this is developed from the lower level of the eye, and extends downward and backward along the maxillary nearly to the ridge of the quadrate, which is a continuation of the preopercular ridge. There is no indication of a stay in any of the other forms.*

The suborbital shelf is in various conditions (see footnote under diagnosis of characters). In some forms it is well developed, in others it is slightly indicated or absent. In *Oligoplites* and some species of *Trachynotus* it is absent. In *Vomer* it is only slightly indicated, and between this condition and a well developed shelf there are all gradations.

The eye has a bony sclerotic case, never so complete or never so dense and thick as in the Scombridae, and often no better developed than in many Percoid fishes.

*The condition of the suborbital bones in *Caranx* and *Oligoplites* suggests the suborbital stay of the mail-cheek fishes. Though in one genus it extends upward across the cheek and in the other downward it springs in each of them from the last suborbital on the lower level of the eye just as it does in the mail-cheek fishes. In this connection it of course signifies nothing, being doubtless a case of parallel development.

The Branchial and Hyoid Arches.

There are three tooth-bearing superior pharyngeals on each side of the last three arches, and a styliiform naked one on the first arch in all of the forms here considered. The first toothed pharyngeal is elongate and lies in front and along the outer edge of the second. The second is always the largest; the third is directly behind it and rather closely joined to it, so that they together form an elliptical plate. The teeth on both the superior and inferior pharyngeals of *Elagatis*, *Oligoplites* and *Naucrates* are fine and sharp. In the others some, or nearly all, of the teeth are blunt molar teeth, particularly on the second toothed superior pharyngeal and along the middle of the inferior pharyngeal.

The inferior pharyngeals lie close together along their inner edges for the greater part of their length and widely diverge posteriorly. In *Elagatis*, *Naucrates*, *Scomberoides* and *Oligoplites* they are less closely attached than in the others.

Trachinotus is an exception to all of the foregoing pharyngeal characters. In this genus the pharyngeals are developed to a remarkable size. In the largest skeleton (*T. kennedyi*, 24 inches long) the first toothed pharyngeal is so reduced as to be practically functionless; it is $\frac{1}{4}$ of an inch wide and half as long. The second is greatly enlarged, being $1\frac{5}{8}$ inches long by half as wide, and $\frac{3}{4}$ of an inch thick. The third is $\frac{7}{16}$ of an inch wide by $\frac{3}{16}$ of an inch long. Each inferior pharyngeal is 2 inches long by half as wide and $\frac{3}{4}$ of an inch thick. The first superior pharyngeal lies at the outer side of the second, considerably behind its front end, while the third is at the posterior end of the second and does not enter into its outline as in the other forms. The inferior pharyngeals and the second toothed pharyngeals of opposite sides meet at the median line and are closely joined to each other, each pair forming an equilaterally triangular plate, so closely joined as to form an almost unbroken surface from side to side. In the superior pharyngeals the triangular shape is less evident, as the outer angles are broadly rounded. The inferior plate is shallowly concave, and the superior correspondingly convex. Except at the anterior end the plates are covered with a smooth pavement, as if the bone, or close-set teeth, had been ground down to a common level. The anterior parts are deeply pitted.

In the young the tooth plates are scarcely so thick correspondingly, and they are pitted all over the grinding surfaces. These bones are apparently not of the same character as the bones that thicken or swell

with age. They are large in all ages, and the base of the skull is expanded to accommodate them.

Three basibranchials are present in all genera, the first in front of the hypobranchials of the first arch and hooking under the glossohyal, as in the family Scombridae. The hypobranchials of the fourth arch are missing, as they almost universally are in bony fishes.

There is nothing remarkable about the hyoid arch. All of the usual elements are present: a glossohyal and urohyal, two hypohyals on each side and a cerato, epi and interhyal. The urohyal bears a longitudinal wing of bone along its lower edge on each side, and the ceratohyal is pierced by a large foramen near its upper edge.

The Shoulder and Pelvic Girdles.

The shoulder girdle shows scarcely any departure from the typical acanthopteroïd arrangement. The pectoral is not placed so near the level of the top of the clavicle as in the Scombridae, and the clavicle does not slope so far forward below it, being more nearly vertical. *Elagatis*, *Seriola*, *Naucrates*, *Oligoplites* and *Scomberoides* approach the condition of the Scombridae in this respect more nearly than the others do, though not very nearly. The clavicle ends above in a point, over which the supraclavicle articulates. Below the point and just above the actinosts a broad, rounded wing is sent back for the support of the postclavicle.

The postclavicle is in two parts, an upper wide, thin bone and a lower long, narrow bone, sometimes long and slender like a typical fish rib.

A large foramen is entirely contained by the hypercoracoid, but either the clavicle or the hypocoracoid may send a lamina of bone to its border on the outer surface of the girdle.

The suture between the hypo and hypercoracoids usually ends between the third and fourth actinosts from the top, but it may vary from the middle of the third to the middle of the fourth, so that $2\frac{1}{2}$ to $3\frac{1}{2}$ of the 4 actinosts are supported by the hypercoracoid.

The hypocoracoid arches away from the clavicle and nearly, or quite, meets it again at its lower end. The clavicle never projects far beyond the lower end of the hypocoracoid as in many of the Scombridae.

A large supraclavicle is always present. The posttemporal is widely forked except in *Trachinotus*. The upper fork broadly overlies the epiotic, and is a little more firmly attached than is usual. It often

extends to, or very slightly encroaches upon, the supraoccipital or the parietal. The lower limb of the posttemporal is attached directly to the opisthotic without the intervention of a ligament. In *Trachinotus* the posttemporal is scarcely forked at all. Its lower end is very wide and its lower fork is exceedingly thick and heavy, being but little produced beyond the general outline of the bone. It forms an unusually broad union with the opisthotic.

The pelvic girdle is in no way notable. Each side rises along its inner edge at the median line to form a low ridge, while at the outer edge each side turns downward and is divided into two longitudinal wings, with often a more or less evident third wing between. At the posterior union of the sides a spine-like process is sent forward below from the base of the ventrals, and above a forked process is sent backward over the base of the ventrals.

The Vertebral Column, Ribs, and Fin Elements.

The number of the abdominal vertebræ in all of the forms here considered is 10. The number of the caudal vertebræ is 14 in all but *Naucrates* and *Caranx chrysos*, which have 15 (though *Caranx hippos* has 14), and in *Oligoplites* and *Scomberoides*, which have 16.

The parapophyses are not developed very far forward. From three to five are usually present, though one or two undeveloped ones may be present in front of these in some forms (they appear so gradually it is difficult to be exact as to the number of developed ones). The last two or three (in *Alectis* one) of them are connected with their opposite fellows by a bridge of bone, leaving a hæmal canal above, and their points projecting separately below. The first hæmal process is differentiated from the last connected parapophyses by being single pointed and much longer and stronger, so that the vertebral column is sharply divided into an abdominal and caudal portion, aside from the indication of this division by the attachment of ribs and anal fin.

Seriola and *Naucrates* are exceptions to these rules. These forms approach the Scombridæ in having the posterior pair of parapophyses united into a single spine, with the ribs at its tip, and the first hæmal process not abruptly enlarged or otherwise differentiated from it. *Decapterus* approaches this condition in having the last pair of parapophyses united into a rounded arch, but with scarcely a spine developed, the ribs not in contact, and the first hæmal process considerably enlarged.

The zygapophyses are usually very large and resemble those of the Scombridæ. On the upper surface of the front of each vertebra a flat

process at each side of the neural canal extends upward and forward, while just below it and separated from it by a notch is a small spine or spur directed forward. On the posterior end of each vertebra a similar spur is directed backward and fits into the notch of the succeeding vertebra. At each end of the lower surface of each vertebra is an inferior zygapophysis; the anterior one projecting over the posterior one of the next preceding vertebra. These are larger in *Megalaspis* than in the others.

In *Megalaspis* the neural and hæmal spines of the tail region become flattened and lie flat each against the surface of the next succeeding vertebra, restricting its movement to a lateral one. From the upper and lower surface of each caudal peduncle vertebra a sharp longitudinal wing is developed laterally, and from the side of each of the 5 or 6 vertebræ preceding the third in front of the caudal a flat spine is produced, forming a broken caudal keel. The caudal fin rays are very deeply cleft at the base, and so broadly clasp the hypural bone as to nearly hide it from sight. *Caranx* approaches this condition, and to a less degree *Trachurops*, *Trachurus* and *Decapterus*. In *Megalaspis* the inferior vertebral foramina are greatly enlarged. These attain their greatest size in the bases of the last parapophyses, where the largest is equal in diameter to the least width of the vertebral centrum just above it. *Caranx*, *Chloroscombrus* and *Gnathanodon* show this condition to a less degree; *Citula*, *Alectis* and *Vomer* have the inferior foramina more or less developed in the bases of the hæmal arches and parapophyses, while in *Decapterus*, *Trachurops*, *Trachurus* and *Selene* the foramina are confined to the hæmal arches.

With the exception of *Seriola* and *Naucrates* and to a much less degree *Trachurops*, *Trachurus* and *Decapterus* the first interhæmal is very large and strong, and is very solidly attached to the equally strong first hæmal process. Often this stay is further reinforced behind by other interhæmal bones, which incline forward against it.

The interspinous rays of the dorsal spines about coincide in number with the neural processes, but those of the dorsal and anal rays are two or three to one of the neural and hæmal processes.

The first two vertebræ bear epipleurals only. The other anterior epipleurals are always on the ribs. The anterior ribs are attached directly to the vertebral centra, sometimes, as in *Trachurops*, *Caranx* and *Decapterus*, in deep pits, whose edges are raised above the body of the centra. *Scomberoides* and *Oligophites* are peculiar in having the ribs attached high on the centra, remote from the parapophyses, except the posterior two pairs, which drop down to the tips of the parapophyses.

MATERIAL.

This paper is based upon the following genera and species:

Oligoplites.

A specimen of *O. mundus*, 18 inches in length, and a cranium of the same species of a specimen 9 inches in length; both from Panama.

Scomberoides.

A specimen of *S. toloparah*, 12 inches in length, from the Philippine Islands.

Elagatis.

A head and shoulder-girdle of a specimen of *E. bipinnulatus*, 31 inches in length, from the Galapagos Islands.

Naucrates.

A specimen of *N. ductor*, 9½ inches in length, from Japan.

Seriola.

A cranium and shoulder-girdle of *S. dorsalis*, of a specimen 3 or 4 feet in length, from San Diego; the cranium 5½ inches long; the vertebral characters described from an alcoholic specimen of *S. zonata*, opened along the vertebral column.

Decapterus.

A specimen of *D. punctatus*, 17 inches in length, from Florida.

Trachurops.

A specimen of *T. crumenophthalmus*, 10 inches in length, from Cuba.

Trachurus.

A specimen of *T. mediterraneus*, 15 inches in length, from the Canary Islands.

Caranx.

A specimen of *C. chrysos*, 14 inches in length, from Cuba, and one of *C. hippos*, 29 inches in length, from the Pacific Coast of Mexico.

Megalaspis.

A specimen of *M. cordyla*, 15 inches in length, from Formosa.

Gnathanodon.

Two specimens of *G. speciosus*, 20 and 25 inches in length, from the Pacific Coast of Central America.

Citula.

A specimen of *C. dorsalis*, 11 inches in length, from Panama.

Alectis.

A specimen of *A. ciliaris*, 14 inches in length, from Cuba.

Chloroscombrus.

A specimen of *C. chrysurus*, 11 inches in length, from Florida.

Vomer.

A specimen of *V. setipinnis*, 13½ inches in length, from Panama.

Selene.

A specimen of *S. vomer*, 16½ inches in length, from Mazatlan, Mexico; one of the same species 5 inches in length, from Maryland, and a specimen of *S. oerstedii*, 12 inches in length, from Panama.

Trachinotus.

A specimen of *T. kennedyi*, 24 inches in length, from Panama; one of *T. carolinus* (with 4 duplicate crania), 7 inches in length, from Maryland, and a head with the locality and species unknown, the cranium 4 inches in length.



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- No. 4. Synopsis of the True Crabs (Brachyura) of Monterey Bay, California. Frank Walter Weymouth. 64 pp., 14 plates. 1910. Price, 50c.
- No. 5. The Osteology of Certain Scombroid Fishes. Edwin Chapin Starks, Assistant Professor of Zoology. 49 pp., 2 plates, 1 text figure. 1911. Price, 50c.

PLATE XIII.

- Fig. 40. *Xanthias taylori* (Stimpson).
♀, nat. size. Monterey Bay, Cal.
- Fig. 41. *Pachygrapsus crassipes* Randall.
♂, nat. size. Monterey Bay, Cal.



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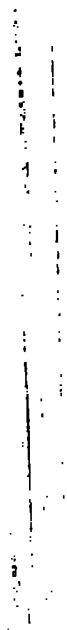


PLATE XIV.

- Fig. 42. *Hemigrapsus nudus* (Dana).
♂, nat. size. Monterey Bay, Cal.
- Fig. 43. *Hemigrapsus oregonensis* (Dana).
♂, nat. size. Monterey Bay, Cal.
- Fig. 44. *Planes minutus* (Linnaeus).
Egg-bearing ♀, nat. size. From floating sea
turtle near the Galapagos Islands.



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No. 5

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CONTENTS.

The Osteology and Relationship of <i>Leiognathus</i> , a genus of Scombroid Fishes	5
The Osteological Characters of the Scombroid Fishes of the Families <i>Gempylidæ</i> , <i>Lepidopidæ</i> and <i>Trichiuridæ</i>	17
The Osteology and Relationships of the Fishes Belonging to the Family <i>Carangidæ</i>	27

1

THE OSTEOLOGY AND RELATIONSHIP OF LEIOGNATHUS, A GENUS OF SCOMBROID FISHES.

BY EDWIN CHAPIN STARKS.

Doctor Boulenger, in his arrangement of fishes in the Cambridge Natural History, has eliminated the family Leiognathidæ from among the Scombroid fishes, where it hitherto has been considered, and has included it in the family Gerridæ, a family of more or less evident Percoid affinities.

That Doctor Boulenger had some reason for this decision any one will admit who makes a comparison of the mouth parts of the members of these two families. Comparing then the genus *Gerres* with the genus *Leiognathus*, which are typical representatives of their respective families, we find these parts almost identical. Both have a long mandible, with a concave lower outline, and a small mouth. The ascending limb of the premaxillary is exceedingly long, extending over the top of the head between the eyes and allowing the premaxillaries to be drawn outward or forward to an enormous degree. The posterior tip of the maxillary lies below the preorbital as an ovoid plate. When the premaxillaries are drawn forward the maxillaries are inclined somewhat forward also.

But aside from the mouth parts these genera have little in common. *Gerres* has large scales over the head and body. *Leiognathus* has very fine scales on the body, and the head and breast are naked and covered with silvery skin suggestive of that of the Scombroid fishes. *Gerres* has a very short anal base; *Leiognathus* a very long one, and the soft rays of both the dorsal and anal fins are arranged each in a step or notch, as in so many of the Scombroid fishes, indicating a tendency towards a breaking up of the fins into finlets.

The following investigation of the osteology of *Leiognathus* was undertaken (1) to learn its skeletal characters; (2) to compare them with those of *Gerres*; and (3) to ascertain what, if any, its Scombroid affinities might be.

have ventured to call the sub-atoms with which electrons are combined the material part of the atom, as distinguished from the electrical part, because the atomic mass seems to be chiefly associated with this part, and mass is regarded as the material constant of nature.

Electrification.

Electrification was assumed by Franklin to consist of an excess or a deficiency of the electrical fluid (which he sometimes called the "electrical fire") which was assumed to exist as a common stock in the earth and all bodies connected with it. A body was positively electrified when it contained an excess, and a body was negatively electrified when it contained a deficiency of this electrical fire. Applying this definition to our present state of knowledge, we may say that a body is resinously or negatively electrified (using negatively as meaning resinously, and not as indicating a deficiency of the electrical fluid) when if put in electrical contact with the earth or with the inside of a hollow conductor on the earth it will lose electrons, and it is vitreously electrified when if placed under similar conditions it will gain electrons.

In this sense, non-electrification is a relative condition. A body may be non-electrified on the earth, when if moved to another planet it might be electrified.

Since this definition is, in a way, a departure from general usage, it may be well to give it further consideration. On the assumption of two electrical fluids it was supposed that these fluids existed in exactly equal quantities in the earth and in bodies on its surface, and that they were capable when combined of so neutralizing all each other's properties that the existence of either or both could not be detected by any known means. This notion of neutralization has been carried over into the single fluid theory, only here the atoms are regarded as essentially electropositive, just as electrons are essentially electronegative, and it has been assumed that there is just a sufficient number of electrons in the world to neutralize, that is, to render non-attractive and non-repulsive, the atoms of bodies.

This assumption seems to be based wholly on the supposed electrical neutrality of the earth as a whole. If it be possible to show that there is no necessity in electrical theory for such a neutral condition, the argument for equivalent numbers of electrons and atoms falls.

lated to the lower edge of the very short symplectic and the epihyal to the interopercle, as described in greater detail elsewhere in this paper.

Leiognathus has three distinct tooth-bearing superior pharyngeals on each side about equal in size. *Gerres* has two: a very small anterior one, and a very large ovoid one behind it, to which the third and fourth arches are very distinctly attached. There are traces of a suture separating off a small, lunate, posterior portion of this plate, but if this portion represents a third pharyngeal element it is entirely behind the fourth arch and unattached to it. The lower pharyngeals of both genera meet broadly on the median line, but are not at all coalesced.

There is no very important difference between the shoulder girdles of these two genera. In *Gerres* the pelvic girdle is wide as in most of the percoid fishes, but in *Leiognathus* it is deep and compressed, with a wing of bone on each side extending forward so that a deep channel is left between them. This resembles the pelvic girdle of most of the Chætonontoid fishes, and of other deep forms related to the Scombroids.

As might be expected these genera are too closely related to show important differences in the vertebral column. They both have 10 + 14 vertebrae. The parapophyses in *Leiognathus* are larger than in *Gerres*, stand out more prominently, and are unconnected at the base. The last pair are anchylosed, and spread out in a broad trowel-shaped bone about the end of the abdominal cavity. In *Gerres* they are as in most of the Percoid fishes—the last three or four with a bony ridge connecting them in pairs at the bases.

Internally, as externally, the long anal of *Leiognathus* is a noticeable difference. The abdominal cavity is very much shorter, with the first interhæmal and hæmal bones vertical, instead of sloping far backwards as in *Gerres*.

In *Leiognathus* there is a very large baseost at the base of each dorsal and anal ray firmly joined, suturally, to the interspinous bones. In *Gerres* baseosts are present in connection with these rays, but they are small, detached nodules of bone.

On the whole these two forms, aside from the similarity between the mouth parts, have no more in common than most any Percoid fish might have with any Scombroid fish. Hence I propose to recognize the Scombroid family Leiognathidæ and the Percoid family Gerridæ.

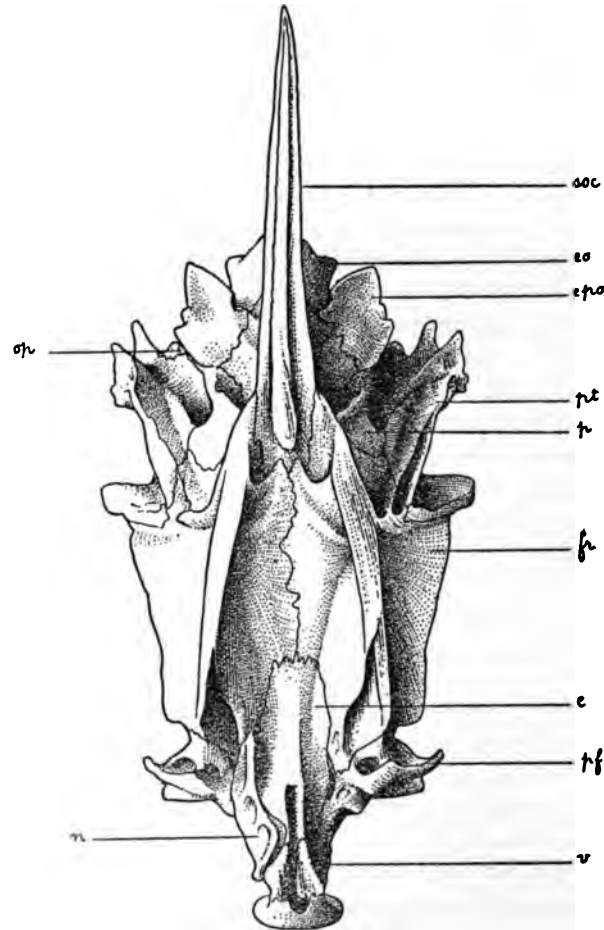
RELATIONSHIP TO THE SCOMBROID FISHES.

That *Leiognathus* belongs with the scombroid fishes there can be little doubt. Its external characters and general appearance, which must be considered, point to such a relationship—to the extent, in fact, that it has often been considered as a member of the family Carangidæ. On the other hand it does not resemble in any way the percoid fishes.

It is not, however, a member of the family Carangidæ, nor is it probably very closely related to it. The gill-membranes are connected with the isthmus in *Leiognathus*. In the family Carangidæ they are free from the isthmus. The suborbital chain is incomplete. In the Carangidæ it is complete. The supraoccipital crest does not extend forward. In the Carangidæ it is carried forward by the frontals for the entire length of the cranium. The alisphenoids are in contact. In the Carangidæ they are separate. *Leiognathus* differs further from the members of the Carangidæ in the peculiar attachment of the hyoid arch to the lateral head bones; in the pelvic arch being deep, and in the very protractile premaxillaries.

Where its relationship lies among the scombroid fishes is more difficult to say. It is probably an abbarrent family like so many others in that relationship. The character of its supraoccipital crest, and its deep pelvic girdle may indicate a connection with the scombroid stem near place where the Chætodontoid fishes branched off.

THE OSTEOLOGY OF LEIOGNATHUS FASCIATUS IN
DETAIL.



SUPERIOR VIEW OF CRANIUM OF LEIOGNATHUS FASCIATUS.

Drawn by C. L. STARKS.

<i>e</i> , ethmoid.	<i>fr</i> , frontal.	<i>p</i> , parietal.	<i>soc</i> , supraoccipital.
<i>eo</i> , exoccipital.	<i>n</i> , nasal.	<i>pf</i> , prefrontal.	<i>v</i> , vomer.
<i>epo</i> , epiotic.	<i>op</i> , opisthotic.	<i>pt</i> , pterygoid.	

On each frontal, beginning at the anterior outer edge just behind the prefrontal, is a high, thick ridge which converges backwards with its fellow of the opposite side, and is continuous with the lateral ridge

of the supraoccipital crest. These and the median supraoccipital ridge are finely sculptured on their upper edges, and in the undissected specimen are externally visible, being covered only with very thin skin. Between the frontal ridges there is a broad median area depressed below the level of the supraorbital region on the outer side of the frontal ridges. From the sphenotic a sharp ridge curves upward to the posterior end of the great frontal ridge, joining it near its union with the lateral ridge of the supraoccipital crest. In the base of the lower end of this ridge is the opening of a sensory tunnel, which curving upward and backward pierces the great frontal ridge, and opens at the posterior end of the frontal near the supraoccipital. This sensory tunnel is in continuation with the suborbital and pterotic tunnels, and also with the frontal tunnel, which runs forward traversing longitudinally the great frontal ridge and thence the nasal.

The supraoccipital extends back in a high triangular crest without either extending forward over the frontals, or being in continuation with a median frontal ridge. Following its entire upper contour on each side is a lateral ridge, which is in continuation with the high ridge on each frontal as described above. Posteriorly the supraoccipital extends down over the exoccipital suture, but it does not reach to the foramen magnum.

The exoccipitals meet both above and below the foramen magnum, and their vertebral articular fascets are nearly in contact above the basioccipital. Each bears three foramina more or less in a horizontal line. The middle one, the vagus foramen, has two smaller foramina close beside it, and the anterior one, the glossopharyngus foramen, is only partially contained by the exoccipital, being between that bone and the prootic. The posterior one, the foramen of the occipital nerve, is situated on the ridge that runs forward from the exoccipital condyle to the pterotic crest.

The whole lower posterior part of the basioccipital is occupied by a very large opening to the myodome, filling the width of the bone and leaving its side walls thin. From the upper posterior edge of the basioccipital is a sharp ridge running downward and forward to its lower edge just in front of the posterior opening to the myodome. Between this and the basioccipital condyle are some pits ending blindly, but resembling neural foramina.

The parasphenoid bears a thin median keel below, behind which is a saddle-shaped notch where on each side the first toothless pharyngeal lies. Just back of this is a swollen knob for the support of the other superior pharyngeals, and still farther back, extending under the knob,

is a deep conical cavity with its apex pointed forward, just as in the genus *Gnathanodon* and in several members of the family Scombridæ, only the myodome does not open into its side, as it does in the Scombridæ. The parasphenoid extends a little behind the front of the posterior opening to the myodome in a little sliver of bone on each side, but it does not reach nearly to the basioccipital condyle. A broad wing is developed upwards along the prootic on each side of the myodome and is strengthened by a lateral ridge continuous with a sharp thin ridge on the prootic and the outstanding wing of the sphenotic. As the prootics and the lower edges of the basioccipital end abruptly against the parasphenoid, without curving inward at all toward each other, the parasphenoid forms the entire lower floor of the myodome.

Through the lateral wing of the prootic is a rather long tunnel—the trigemino-facialis recess, running from the middle of the preorbital surface of the bone forward, and opening on the orbital surface. A foramen opens into this recess at about its middle on the postorbital surface just below the articular cup of the hyomandibular.

The alisphenoids meet and divide the anterior opening of the brain case into two parts—a lower round part, and an upper, much larger, triangular part.

Bordering the posterior half of the lower opening is the basisphenoid. It is connected with the prootic roof of the myodome for its full width without an opening between. It sends down a long process to the parasphenoid.

The sphenotic stands outward in a very prominent lateral wing behind the eye, and is continuous with the frontal supraorbital border. To its outer edge is attached one of the suborbital sensory tube bones, which reaches upward to the frontal.

The opisthotic is almost wholly on the inferior surface of the cranium, though a portion of its thickened posterior end is visible from above. It covers the pterotic-exoccipital suture, and no part of it is interposed between the pterotic and exoccipital. The broad lower limb of the posttemporal is firmly attached to it without the intervention of a ligament.

The parietals are widely separated by both the supraoccipital and the posterior points of the frontal which project backwards. They are situated just above and anterior to the epiotics. Each is in outline an irregularly round bone, and is traversed by a sharp wing running from just behind its middle upward to where the frontal joins the supraoccipital ridge.

The epiotic is round in outline and elevated at its middle where the posttemporal broadly and firmly articulates with it. It sends back a thin horizontal shelf.

The pterotic bears a wide ridge running obliquely upward from its posterior end to the posterior end of the frontal. It bears a sensory channel which is inclosed as a tube along its lower half, and is a deep open canal along its upper. At its upper end this is in communication upward with the frontal system of sensory tunnels, and downward along the sphenotic with the suborbital system. At its lower end it communicates backward through the supratemporal with the lateral line along the side of the body, and downward with the preopercular system.

The prefrontals are not in contact with each other, though they are separated only by a small area of cartilage—apparently an unossified part of the ethmoid cartilage. Each is pierced by the olfactory foramen. Near the upper end of each are two blunt spines, and the lower end is a facet for the articulation of the palatine. The spines are apparent externally through the skin in the undissected specimen.

The ethmoid lies between the prefrontals and the anterior end of the frontals, separating the latter for a considerable distance. It may be seen from below forming part of the orbital roof. In its anterior part, on the superior surface of the cranium, an area of cartilage extends forward and is continued along the posterior half of the vomer. This in the dried skeleton shrinks and leaves an open channel.

The vomer is toothless and ends below at its anterior end in a double point.

The nasals are slender, crooked bones continuing the sensory tube from the frontals and carrying it forward.

The suborbitals are represented by a preorbital plate and by some thin, delicate bones behind the eye, but the chain is incomplete below the eye. A long slender one extends up the side of the sphenotic, carrying the sensory tube up to the frontal, where it communicates with the pterotic sensory tube and with the frontal tube.

The supratemporal is an inverted T-shaped, tube-bone, its horizontal branch continuing the lateral line to the pterotic sensory tube, its vertical branch running upward to the top of the head at the side of the supraoccipital just under the skin. Thence it runs backward along the side of the supraoccipital spine nearly to the interneurals, resembling the auxiliary branch of the lateral line common to many flounders.

The hyomandibular is a long, rather simple bone, with a process behind for the articulation of the opercle, and without a process to the

metapterygoid. Its lower end is at a considerable distance from the symplectic.

The palatine is firmly articulated to the lower edge of the prefrontal, and bears a process which hooks over the maxillary.

The symplectic is a short, small, triangular sliver of bone occupying a notch in the posterior angle of the quadrate. On its lower edge not far from its posterior end is a cup-shaped cavity for the reception of the interhyal.

A well developed angular is present and forms the lower posterior angle of the articular. The articular and dentary are loosely attached to each other so that they are slightly independently movable in the undissected specimen. The tooth-bearing portion of the dentary does not reach nearly back to the middle of the upper edge of the bone, which in most forms is completely toothed. The gape of the mouth is restricted to this portion, while the posterior portion is covered by the end of the premaxillary upon which it hinges. Hence the lower jaw attached at its posterior end as usual, and the premaxillary attached to it in front of its middle, the fish can only open its mouth by projecting the long premaxillary processes forward from their sheath. In most fishes the maxillary elements if attached at all to the lower jaw are attached so far back, or so loosely, that the opening of the mouth only effects the posterior end of them at the most. There are many examples of intermediate conditions between those described above. The mouth of *Capros* and of many fishes of the family *Chatodontidae* approaches rather closely the condition of *Leiognathus*.

The maxillary is a complex-shaped bone, shaped roughly like the figure 3. It meets its fellow above the premaxillary process, and nearly meets it below, thus forming a sheath in which the process moves.

A small, round nodule of bone represents the interhyal. It is rather firmly bound down to the epihyal by tissue. It fits into the cup-shaped cavity in the lower edge of the symplectic remote from the hyomandibular, instead of between the hyomandibular and the symplectic as is the usual arrangement. But the chief articulation of the hyoid arch to the lateral head bones is through the interopercle. This element is thickened along its upper edge, and about midway in its length is a prominent facet, partly sunk below the surrounding surface of the surrounding bone and partly raised above it. To this the posterior end of the epihyal is firmly articulated by a specialized articular facet. The hypohyals are paired on each side. A glossohyal and urohyal are present, the latter with wings standing out horizontally from its lower edge.

There are three tooth-bearing superior pharyngeals on each side.

The inferior pharyngeals are broadly in contact but are not co-ossified. Just in front of them the ceratobranchial of the fourth arch becomes compressed and as thin as paper. The hypobranchial of the last arch is missing. Two basibranchials are ossified.

The clavicle extends far below and anterior to the lower end of the hypocoracoid, as it does in members of the family Scombridæ. Its lower end is broad and rounded. At the middle of its length a thin, vertical plate extends inward, nearly meeting its fellow of the opposite side, and forming a partition behind the branchial cavity. At the outer edge of the clavicle are two triangular projecting points, which show prominently just under the gill cover of the undissected specimen. A process is developed backward from the upper edge of the clavicle for the suspension of the postclavicle.

The hypocoracoid is small, and arches away from the clavicle to rejoin the latter at its lower end, inclosing a space between as is usual.

The hypercoracoid is pierced at its middle by a large, round foramen, but this element sets so far behind the clavicle that the clavicle appears to bound the foramen at its anterior edge when viewed from the outer surface of the shoulder girdle.

The actinosts increase in size downward, and have a small hole between each pair. The upper edge of the pectoral works directly on the edge of the hypercoracoid. Two of the actinosts are on the hypercoracoid and two on the hypocoracoid.

The postclavicle is in two parts—the lower part lance-head-shaped and a little wider than usual.

The post-temporal is rather widely forked, and joined to the cranium without the intervention of ligaments on either fork. The supraclavicle is present below it.

The pelvic girdle is attached closely between the clavicles. From the base of each ventral spine a long spine projects forward just beneath the skin of the breast, and is stiffened above by a wide web of bone between it and the main part of the girdle, thus inclosing between them a deep cavity at the front of the girdle. Posteriorly above the ventral fins each part of the girdle sends back a stout spine which is suturally united with its fellow into a single spine.

At the base of each anal and dorsal ray is an exceedingly large baseost. Each of these is firmly united by suture to two interspinous rays, so that each of the latter bears two halves of a baseost. These project outward between the rays making the steps or notches into which the rays fit that are referred to at the beginning of this paper.

The baseosts are not evident at the bases of the anal and dorsal spines—probably becoming co-ossified with the interspinous bones. An auxiliary interneural is in front of the first spine-bearing interneural.

There are ten abdominal and fourteen caudal vertebræ, including the hypural.

Anteriorly the neural processes are wide—nearly as wide as the length of their vertebral centra, and each is channeled on its anterior edge to receive the edge of the next preceding neural process. Posteriorly they become more slender and wider apart. They nearly coincide in number with the spine-bearing interneurals, but they are only half as numerous as the ray-bearing ones, as are also the hæmal processes as compared with the interhæmal rays.

The first developed parapophyses occur on the fourth vertebra, though a rudimentary pair is present on the third. They gradually become longer posteriorly to the last pair, which are expanded into a broad, trowel-shaped shield united to each other at the median line and inclosing the end of the abdominal cavity. The parapophyses are not connected by a transverse bridge across the base of each pair.

Inferior and superior zygopophyses are well developed. The interspinous bones of two vertebræ anterior to the hypural assist in supporting the caudal.

The first two vertebræ have epipleurals only. Anteriorly the epipleurals are attached to the bases of the ribs, but posteriorly they creep up to the vertebral centra. They are present behind the abdominal cavity for a considerable distance.

1. The first part of the document is a list of names and dates.

THE OSTEOLOGICAL CHARACTERS OF THE SCOMBROID FISHES OF THE FAMILIES GEMPYLIDÆ, LEPIDOPIDÆ AND TRICHIURIDÆ.

BY EDWIN CHAPIN STARKS.

The descent of the family Trichiuridæ from the Gempylidæ through the Lepidopidæ was long ago pointed out, and the following results of an osteological comparison between these families only go to strengthen the evidence in favor of this relationship, though the descent is not in a direct line, if we can take *Promethichthys* as a typical representative of the family Gempylidæ.

Promethichthys is more closely related to *Scomber* than to any other existing genus of the family Scombridæ, or at least *Scomber* has retained more ancestral characters of *Promethichthys* than any other member of its family has. These two genera are alike in the character of the cranial crests; in having the opisthotic at the lower surface of the cranium not separating the exoccipital from the pterotic; the suborbital ring complete and bearing a sensory tube; and the caudal peduncle without a lateral keel.

That *Lepidopus* and *Trichiurus* did not come, however, directly from *Promethichthys*, but from some form that has begun to develop in the direction of *Scomberomorus*, is shown by the opisthotic interposed between the exoccipital and the pterotic, and the incomplete suborbital ring and sensory tube. This ancestor may have been *Gempylus*, a form I have been unable to obtain, but showing a development towards the elongate forms of *Lepidopus* and *Trichiurus*.

In view of the extremely close osteological resemblances between the families Lepidopidæ and Trichiuridæ it is with much hesitation that the former family is recognized here. The former family differs from the latter chiefly in the possession of a caudal fin, but when it is considered that this fin, in *Lepidopus*, though well developed, is not very strongly supported, and being at the end of a long, weak, ribbon-shaped body, is probably of little assistance, its loss does not appear of great importance.

The three families here considered differ but little from the family Scombridæ. The eye has no bony sclerotic case, there are no separate bony basecosts, and the caudal rays are not deeply divided at the base to receive the hypural plate.

These three families have the following characters in common: prefrontals meeting at the median line, with the ethmoid appearing nowhere between them posteriorly; alisphenoids separated from each other; supraoccipital extending over the epiotic suture, but not separating epiotics as viewed from within the cranium; myodome and basisphenoid present; the latter with a descending process; eye without a bony sclerotic case; ascending processes of premaxillaries not developed; supplementary maxillary present; teeth in alveoli; coracoid suture ending at middle of third actinost from top; head of hyomandibular divided into two parts; symplectic joined to metapterygoid by a dentate suture; three pairs of tooth-bearing pharyngeals present; the anterior basibranchial remote from the first hypobranchial; anterior ribs and epipleurals attached to vertebral centra; caudal rays, when present, not deeply divided.

The principal characters that differentiate these families is shown in the following synopsis:

GEMPYLIDAE (*Promethichthys*)

The pterotic and temporal crests coterminous against an oblique ridge from the supraoccipital; myodome opening posteriorly through a rather broad foramen; opisthotic on lower surface of cranium not separating the exoccipital from the pterotic; suborbital ring complete and with a sensory tube; pelvic bones attached between clavicles; no parapophyses present, but hamal arches developed behind middle of abdominal portion of vertebral column; no sharp ridge along the side of vertebræ; ribs anteriorly in pits on centra, posteriorly at tips of abdominal hamal spines with their bases in contact as in the family Scombridæ; body incased in two series of intermuscular rays, the upper series composed of epipleurals.

LEPIDOPIDAE (*Lepidopus*)

The temporal crest ending as in *Promethichthys*, but the pterotic crest ending against middle of temporal crest; myodome opening posteriorly through a very small pore; opisthotic partly on superior surface of cranium, and separating exoccipital from pterotic for a con-

siderable distance; suborbital ring not complete, and without a sensory tube; pelvic bones represented by a pair of long, simple rays lying free just beneath the skin remote from the shoulder girdle; no abdominal hæmal arches present; small, slender parapophyses present on last two vertebræ; a sharp keel running along side of vertebræ for nearly whole length of vertebral column; body not incased in rays of bone, and only four or five epipleurals present anteriorly.

TRICHIURIDÆ (*Trichiurus*)

Skeleton differing from *Lepidopus* in having no pelvic bones (not represented in all *Lepidopidæ*); in having the tail taper to a point which is without hypural bones or caudal fin; and in having the weak anal reduced to short, stiff spines.

In the following descriptions the osteology is given in detail.

PROMETHICHTHYS.

A specimen of *P. prometheus* from the Canary Islands, 17 inches in length.

The cranium is elongate and the preorbital portion is somewhat produced. The crests and ridges on the superior surface form a complicated pattern, but in general resembling those of *Scomber*, having an oblique ridge from the supraoccipital against which the temporal and pterotic crests stop. This ridge is forked in front of the temporal crest, and the inner branch runs forward to the ethmoid, while the outer reaches the edge of the cranium above the front of the eye. The myodome opens through a round foramen posteriorly. The occipital region is not produced as in *Scomber*.

The exoccipitals meet broadly over the basioccipital, and have large condyles overhanging the latter. The supraoccipital extending down over the suture between the epiotics and the upper part of the exoccipitals appears from the exterior to separate them, though both the epiotics and exoccipitals meet for their full length within the cranium as in the *Scombridæ*.

The supraoccipital crest is but little developed. It is considerably behind the eye and not very far anterior to the occipital condyle. It is not formed at all by the frontals anteriorly, and scarcely rises above the level of the temporal crests. It has no sharp apex directed upward as in *Lepidopus*.

The basisphenoid is present and has a descending process to the parasphenoid. The alisphenoids are widely separated by the anterior opening to the brain cavity. The prefrontal is elongate and meets its fellow of the opposite side at the median line in front of the orbital cavity. It has the usual lateral wing which is pierced by the olfactory nerve and supports the posterior end of the palatine below. In front of the prefrontal a lateral protuberance is formed by the vomer and ethmoid and extends up nearly to the frontal. The vomer is obliquely truncate on each side for the articulation of the maxillary. The opisthotic is on the lower surface of the cranium covering the exoccipital-pterotic suture, and scarcely showing on the superior surface. To its posterior edge the lower limb of the post-temporal is attached.

The nasals are rather wide and are attached to the front of the frontals and ethmoid. They are produced anteriorly in front of the ethmoid over the maxillary. The preorbital is long and carries a sensory tube in continuation with that of the suborbitals. The suborbitals are little more than a chain of small bony tubes, but they form a complete suborbital ring. There is no suborbital shelf, and the eye is not incased in a bony sclerotic cup.

The premaxillary bears only a slight suggestion of an ascending process. The maxillary carries a long, narrow, supplementary maxillary along its upper edge. The anterior inner end of the maxillary has a conspicuous fascet for articulation with the vomer. The teeth on the side of the premaxillary are set in alveoli, but the long lance-like canines, forming a short inner row in front, though developed from cavities are of a different character, as the cavities behind them become filled with "bone of attachment" as the teeth are pushed out.

The head of the hyomandibular is divided into two parts, though a little less completely than in the Scombridae. The opercular elements are not so smoothly united to each other. The upper part of the symplectic is united to the metapterygoid by a dentate suture as in *Sarda* and *Thunnus*. The palatine is armed with a single row of small sharp teeth, and anteriorly the usual process extends over the maxillary. The articular entirely fills the notch in the dentary; a small angular is present. The teeth at the side of the dentary resemble those of the premaxillary, but one or two teeth at the front are apparently of the character of the inner premaxillary row.

The posttemporal is a slender, widely forked bone. Its upper limb is rather solidly attached to the epiotic, and slightly overlaps the parietal, but it does not impinge on the supraoccipital as in some of

the Scombridæ. Its lower fork is attached to the posterior edge of the opisthotic. A well developed supraclavicle is present. Above the pectoral the clavicle is bent at a considerable angle, allowing the body of the shoulder girdle to extend forward even more horizontally than in the Scombridæ. The hypocoracoid foramen is large and at the center of the bone. The hypocoracoid differs from that of the Scombridæ in reaching downward to the end of the clavicle. The actinosts are a little longer and more slender than in *Scomber*, but arranged the same in relation to the coracoid elements, the third from the top being opposite the coracoid suture. There is no wing from the clavicle above the pectoral fin to support the postclavicle. The superior element of the postclavicle is very short and firmly attached to the clavicle; the inferior element is long, slender and slightly expanded below, the two portions appearing as a single piece.

The pelvic girdle is very long and slender, extending forward to between the clavicles and attached in the way usual to thoracic ventrals.

As in the Scombridæ, there are three basibranchials; the anterior one remote from the hypobranchial of the first arch. Four pairs of superior pharyngeals are present; the first toothless; the second long and narrow and lying beside the third; the third the largest; and the fourth in line behind it, and lying so close that the third and fourth form an almost continuous tooth patch, though they are not so closely connected as in the Scombridæ.

The glossohyal and urohyal are both present; the latter without lateral ridges. A pair of very large hypohyals are present on each side; a long ray of bone from the ceratohyal extends under them to support the anterior branchiostegal ray. Four branchiostegal rays are upon the ceratohyal and three upon the epihyal.

There are 20 abdominal vertebræ and 13 caudal, or a total of 34 with the hypural. There are no parapophyses, but on the 11th vertebra there is a small, round, hæmal arch, formed by connected parapophyses, as in the Scombridæ. It is without a spine, is inclined forward, and is longitudinally flattened. Posteriorly the abdominal hæmal arches gradually develop a spine and incline backward. The ribs are set in sockets anteriorly low on the centra of the vertebræ, and posteriorly are carried at the tips of the hæmal arches, each pair with their bases in contact as in the Scombridæ. Each rib or hæmal arch is placed almost directly at the middle of the vertebra. The neural arches are more posterior, but still at some distance from the ends of the vertebræ.

Two series of long, slender bones lie just beneath the skin and incase the body, one series above and one below the middle of the side. The upper series is composed of the epipleurals, which curve outward to the skin and then upward nearly to the dorsal. The lower series is an extra intermuscular ossification, and is perhaps not present in the young, as is the case with a similar ossification in the genus *Chanos*. The first two vertebræ bear epipleurals only. On the third vertebra and some of the succeeding ones the epipleurals and ribs join the vertebræ together, with their bases connected, but a short distance back the epipleurals lose all connection with either ribs or vertebræ and lie loose in the intermuscular connective tissue. The last two or three vertebræ are as in *Scomber*, not abruptly shortened as in most of the Scombridæ. There is no trace of a lateral caudal keel. The hypural bears a large urostyle.

The upper ends of the interneurals of the spinous dorsal are laterally expanded, and probably represent the anchylosed baseosts. No separate bony baseosts are present in any of the fins. The bases of the caudal rays are not deeply divided, nor are the rays widely divergent as in most of the Scombridæ.

A skiograph of *Epinnula magistralis* from a specimen in the U. S. National Museum shows the number of vertebræ to be 15 + 17 (counting the hypural); the ribs are borne at the tips of the abdominal hæmal spines; the body is not incased in a series of intermuscular rays, as in *Promethichthys*, and the ventral fins are attached to slender pelvic bones which extend between the clavicles.

LEPIDOPUS.

A specimen of *L. caudatus* from the Canary Islands, measuring 3 feet in length.

In this form the supraoccipital crest is far anterior to that of *Promethichthys*. As viewed from the side of the cranium it rises as a stout triangular process far above the rest of the skull, with its sharp apex directed upward. It is over the posterior part of the orbital cavity, or nearly a fourth of the distance from the occipital condyle to the tip of the vomer. The frontals form the anterior part of it. The ridges, which in *Promethichthys* are low, and run from the front of the supraoccipital obliquely to intercept the temporal crest in *Lepidopus*, are high, sharp ridges, starting at the apex of the supraoccipital crest and running more directly forward. Deep between them is a small median ridge representing the front part of the supraoccipital crest.

Instead of the pterotic and temporal crests being coterminous anteriorly, the latter ends against the middle of the former, which continues alone to the ridges from the supraoccipital. The epiotics meet very broadly behind the supraoccipital, but a thin sheet of bone from the supraoccipital extends over the median suture between them and reaches down to the exoccipitals. The sheet of bone is so thin and transparent that it is difficult to see it, and the outline of the epiotics is clearly to be seen through it. The ethmoid is not at all posterior to the front of the vomer. The lateral process of the parasphenoid ends as a free point nearly reaching the alisphenoid. The opisthotic separates the exoccipital from the pterotic to a considerable extent, and the lower limb of the posttemporal is attached to its superior surface a little before its posterior edge. The myodome is nearly closed posteriorly. With these exceptions the cranium is very similar to that of *Promethichthys*.

The suborbital ring is incomplete posteriorly, and there is a suborbital shelf loosely attached to the bones anterior to it. The preorbital is large and traversed by a sensory tube, which is not in continuation with the suborbitals.

The maxillary and teeth are essentially as in *Promethichthys*. The middle portion of the maxillary projects behind in a thin wing, and the supplementary maxillary is not very large.

The head of the hyomandibular is widely divided into two portions. The opercle and subopercle are made up posteriorly of radiating rays of bone, which stand apart like bristles when the tissue connecting them is removed. The symplectic is suturally connected with the metapterygoid, and all of the lateral head bones are almost identical with those of *Promethichthys*.

As the cranium extends backward below the upper limb of the posttemporal farther than in *Promethichthys*, the lower posttemporal limb is not in consequence so long. A tube bearing supratemporal is present.

The portion of the clavicle above the pectoral fin is nearly as long as the portion below, and is turned at a right angle to the latter. The hypocoracoid is thin and much produced backwards. The actinosts are shorter than in *Promethichthys*, but arranged the same in reference to the coracoid elements, and the arrangement of the postclavicle is the same.

The pelvic bones are long, simple rays, lying just beneath the skin, remote from the shoulder girdle. The flattened or scale-like ventral

spines are attached at about the anterior third of the length of the pelvic bones.*

The branchial and hyoid elements are almost identical with those of *Promethichthys*.

There are 41 abdominal vertebræ, and in the specimen at hand 62 caudal, besides a few (probably not exceeding 5) that are missing at the end of the tail.

Lepidopus differs from *Promethichthys* in having no abdominal hæmal arches. The last two abdominal vertebræ bear small, slender parapophyses, but the ribs are still attached to the vertebral centra at the base of them, though they are also attached to the full length of the parapophyses at the side. The abdominal hæmal arches and spines in *Promethichthys* are not differentiated from those of the caudal region, but in *Lepidopus* the change from the small parapophyses of the last abdominal vertebræ to the large hæmal arch and spine of the first caudal vertebra is very abrupt. The ribs are set in very deep pits low on the vertebral centra, and, as in *Promethichthys*, each rib or hæmal spine occupies a position at about the middle of the length of its vertebra. There is a sharp, low, lateral ridge running the length of the vertebral column. Along the caudal region it occupies the middle of the sides of the vertebræ, and is a little elevated at each end of each vertebra. On the abdominal region it is ventral in position, and forms a sharp lower edge, which bears the sockets for the ribs.

The first two vertebræ bear epipleurals only. There are only three other epipleurals attached to the vertebral centra just above the base of the ribs. There are no long intermuscular bones incasing the body, as in *Promethichthys*. The hypural is small, but in no way remarkable; the caudal rays are not deeply divided. The interneurals are T-shaped, with the horizontal limb connecting them, and forming the outline of the back. They are only slightly expanded laterally just beneath the skin. No ossified, separate baseosteos are present. The fourth and fifth interneurals bear large bean-shaped swellings near the upper end, each nearly as large as a vertebra.

*The abdominal ventrals might indicate a direct descent from more primitive forms with similar ventrals, did not *Promethichthys* (with thoracic ventrals) so obviously stand between. This condition in *Lepidopus* probably shows an independent degeneration or modification. As the body has become elongate, and the ventrals functionless, the latter have lost their connection with the shoulder girdle and have moved backwards. Since the above was written a paper by Mr. C. Tate Regan (Ann. and Mag. Nat. Hist. (8) Vol. III. 1909) has been received in which he has come to the same conclusion: "This condition may be regarded as secondary and due to the degeneration of the fins."

TRICHIURUS.

A specimen of *T. lepturus* from Jamaica, 32 inches in length; a head and partial skeleton of a slightly smaller skeleton from Virginia, and a head and shoulder girdle of a specimen, about the same size as the first, with the species and locality unknown.

In the first specimen the sutures separating the cranial bones are well marked and the clavicle is normal. In the second specimen the frontals, parietals, epiotics and supraoccipital have become covered with spongy bone substance, thickening them and uniting them into a single piece. The clavicle is normal. In the third specimen the frontals have become ankylosed, but not thickened, and well marked sutures separate the other bones. In this specimen the lower part of the clavicle is very much swollen, so much so that the usual deep channel along its posterior edge is filled in. This bone thickening does not appear to be of the same character as that of the cranial bones of the second specimen, where the thickening appears to be a superficial, soft, cellular deposit. In the clavicle the surface of the swollen portion is the same as that of the unmodified portions, as if it were a regular periosteal deposit.*

The skeleton of *Trichiurus* scarcely differs from that of *Lepidopus*. The front of the skull is nearly devoid of ridges extending forward from the supraoccipital. The supraoccipital extends more broadly over the epiotics than in *Lepidopus*, appearing to widely separate them, though they meet within the cranial cavity.

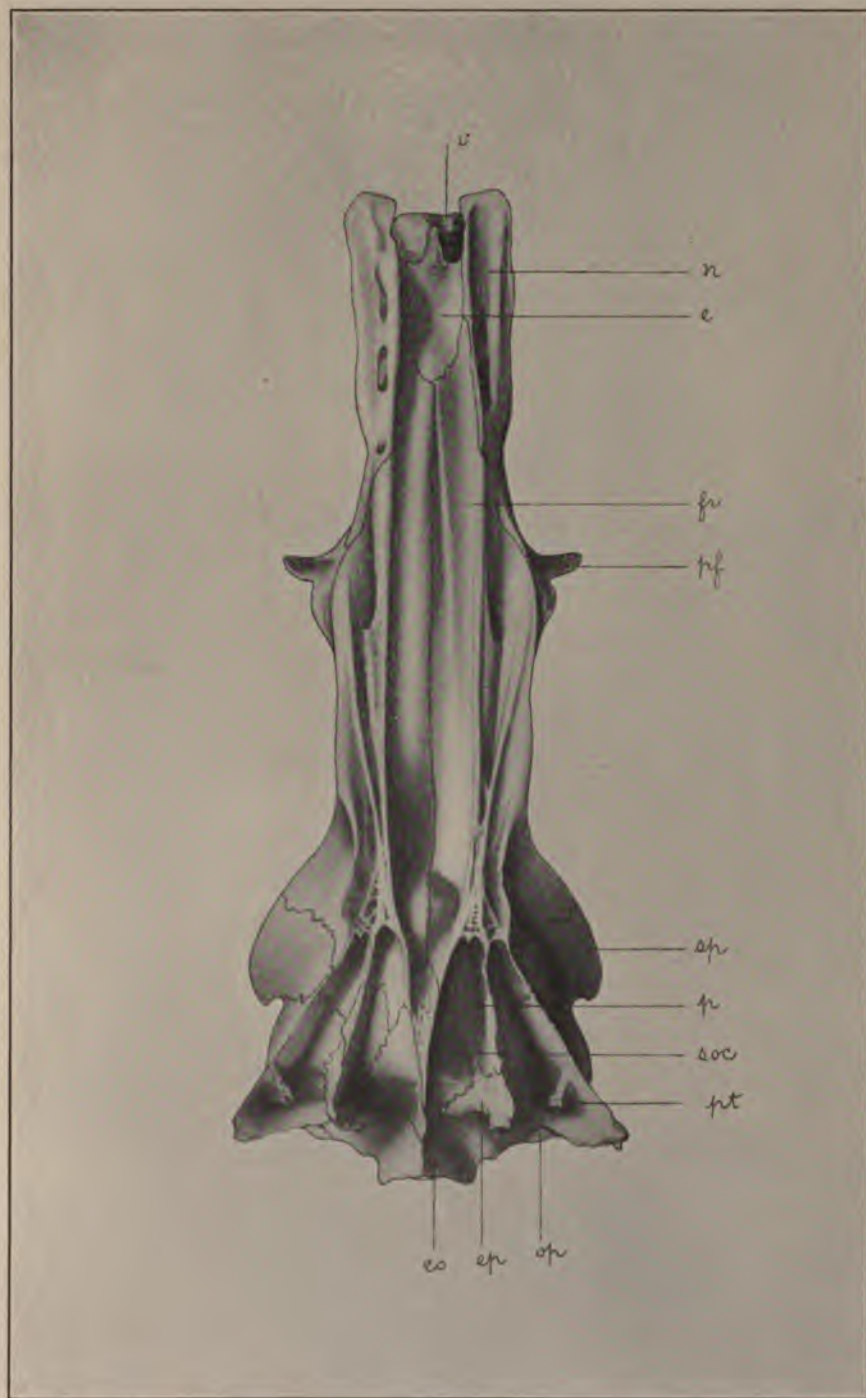
The suborbital ring is represented by the preorbital and one ossicle behind it, with a third at the posterior margin of the eye unattached to the others. The last is developed inward as a thin wing, so that it is apparently the suborbital shelf, but shifted backward from its position in *Lepidopus*. There is no suborbital sensory tube.

The maxillary elements and lateral face bones are identical with those of *Lepidopus*. The teeth differ only in being larger and occupying deeper pits. The hypocoracoid is not broad and produced backwards abnormally, and the postclavicle is more slender. The shoulder girdle and its attachment is otherwise as in *Lepidopus*. The pelvic

*I have examined a number of specimens in the collections of Stanford University for a similar condition of the clavicle, and find it only in a specimen from China labeled *Trichiurus japonicus*. This condition may be of enough importance to separate its possessors into another genus. It is apparently a condition parallel to that of *Melanogrammus*, which has been separated from *Gadus* by a similarly swollen hypocoracoid. Sufficient material is not at hand to decide whether it is a development with age.

bones are entirely absent. The hyoid and branchial arches differ in no way from those of *Lepidopus*.

There are 39 abnormal vertebræ, and 100 caudal vertebræ may be counted to where the tail tapers to so fine a point as to make counting difficult. The vertebræ are much shorter than in *Lepidopus*, and in consequence the neural and interneural bones are at shorter intervals and with shorter arms between the fin rays. The lateral ridge along the vertebral column is much higher and sharper, the anal is represented by very small sharp spines, there are no swollen interneurals, and the tail tapers to a point without a hypural bone or caudal fin. Otherwise the vertebral column and fin elements are nearly identical with those of *Lepidopus*.



PROMETHICHTHYS PROMETHEUS.

C. L. STARKS, del.



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MUTUAL RELATIONSHIP.

The family Carangidæ is a much more compact group than the Scombridæ. The gaps between the genera are much smaller, and though the osteological characters, like the form of the body, differs much in the extremes of variation, there are no sudden or complete changes. Consequently the genera do not so readily group themselves into subfamilies as do the genera of the Scombridæ. Though the groups here indicated are not very definite, they may show at least relationship.

The subfamily Scombroidinæ contains the genera *Oligoplites* and *Scomberoides*. It may be distinguished by the non-protractile premaxillaries, the presence of many finlets, the broad union of the epiotics within the cranium, the slightly increased number of vertebrae, and the ribs (except the posterior two or three pairs) attached high on the side of the centrum, not even in contact with the parapophyses.

Oligoplites and *Scomberoides* do not resemble each other so closely as might be expected from their close external resemblance. The latter differs from the former in having a supplemental maxillary. In *Scomberoides* the temporal crest reaches far forward to above the prefrontal, while in *Oligoplites* it ends over the posterior part of the eye. In *Scomberoides* the top of the cranium is deeply concave at each side of the supraoccipital crest above the eye, while in *Oligoplites* it is flat. In *Scomberoides* the exoccipital condyles are broadly in contact, while in *Oligoplites* they are separate. *Scomberoides* has a well developed subocular shelf, which in *Oligoplites* is absent.

The Naucratinæ includes *Naucrates*, *Seriola* and *Elagatis* (the vertebral column of the last has not been seen). This group is distinguished by having the first interhæmal unenlarged, the last one or two pairs of parapophyses each united to form a hæmal arch and spine, at the tip of which the ribs are attached with their bases in contact, the first hæmal spine unenlarged and not firmly attached to the first interhæmal, the lateral line not abruptly arched, and the anal not preceded by two free spines. In the other Carangoids the posterior parapophyses are distinct, not united as a single hæmal spine, though a bridge of bone connects their bases.

Decapterus in the condition of the posterior parapophyses approaches this character. It shows an alliance to *Elagatis* in the pos-

session of finlets, and should perhaps be included in this subfamily, or else these two genera might be considered together as a separate subfamily characterized by the possession of finlets.

All of the other forms considered, except *Trachinotus*, are here included under the Caranginae. It is even less satisfactory to try to divide them than in the case of the others, and though *Selene* is not nearly so closely related to *Trachyurops*—for instance—as some forms are to each other that are here arranged in different subfamilies, there is no place to draw a dividing line. There seems no good reason for recognizing the Chloroscombrinae.

The Caranginae may be characterized by the strong first interhæmal process firmly united with the strong first hæmal process and together forming a long curved brace bordering the abdominal cavity behind, as in the flounders. In *Decapterus*, *Trachyurops* and *Trachurus* this character is not so well marked as in the others, and it is a character of all of the Carangidae except the Naucratinae. The Caranginae have the lateral line abruptly arched in front, and usually armed with keeled plates, and there are usually two detached spines in front of the anal.

The Trachinotinae contains only the genus *Trachinotus* and is a well defined subfamily. It is placed at the end of the series, as it has no characters to show from where it may have branched from the other Carangoids.

It is characterized by having the snout region shortened; the maxillary without a supplemental bone; the posttemporal but little forked; the opisthotic separating the exoccipital from the pterotic to a greater extent than in the other genera; the pharyngeals enormously developed, with the parasphenoid expanded to accommodate the superior ones; and with the posterior opening to the myodome reduced to a pore or obsolete.

DIAGNOSIS OF CHARACTERS.

Supraoccipital crest carried forward to ethmoid by the frontals. Supraoccipital variously separating epiotics, or not at all, as viewed from within the cranium.

Exoccipitals meeting above and below, always for their full length above, and broadly below, or in most cases for their full length. Pre-frontals broadly meeting at the median line; each pierced for the passage of the olfactory nerve.

No auditory bulla apparent externally.

Temporal crests well developed, and usually reaching the edge of the cranium above the orbital cavity.

Myodrome large and (except in *Trachinotus*) opening to the exterior posteriorly.

Opisthotic sometimes interposed more or less between the exoccipital and pterotic, but usually scarcely at all, and never to the extent that it is in the Scombridæ.

Basisphenoid present and with a process descending to the parasphenoid. Eye with a bony sclerotic case not so well developed as in most of the Scombridæ.

Suborbital ring complete and with a sensory tube; a suborbital shelf variously developed or absent.*

Nasals well developed and projecting.

Premaxillaries protractile in all but the Scombroideinæ; their ascending processes of varying length from moderately short to very long.

Maxillary with a supplementary element on its upper posterior edge in all but *Oligoplites* and *Trachinotus*.

Preopercle unarmed except in the very young.

Head of hyomandibular, where it joins the cranium, more or less divided into two parts.

Four pairs of superior pharyngeals present (three with teeth).

Three basibranchials, the first in front of the arches and extending under the glossohyal.

Clavicle more nearly vertical than in the Scombridæ, extending farther above the pectoral fin, and not so far anteriorly; never projecting much in front of hypocoracoid at its lower end.

Actinosts, 4; moderately short; $2\frac{1}{2}$ or $3\frac{1}{2}$ of them on hypercoracoid.

Postclavicle in two parts.

*The worthlessness of the character of the presence or absence of the suborbital shelf, which has been used in taxonomy, is shown by *Oligoplites* and *Scomberoides*—two genera of undoubted close relationship. In the latter genus the shelf is well developed and in the former it is absent. It may, furthermore, even vary within a genus. In *Trachinotus kennedyi*, from the Pacific Coast of Central America (five specimens examined from 8 to 20 inches in length) there is no suborbital shelf developed. While in *T. rhodopus*, from the Pacific Coast of Central America (five specimens examined from 6 to 12 inches in length), and in *T. glaucus* and *T. carolinus* from Florida (one specimen of each 12 and 18 inches in length) there is a well developed suborbital shelf. It is not coössified with the suborbital chain but connected by tissue. In *T. ovatus* from Formosa, however, (a specimen 30 inches in length) the shelf is large and firmly coössified with the suborbital bone that bears it.

Vertebrae in small numbers; the abdominal always 10; the caudal from 14 to 16 (usually the former).

Parapophyses not developed very far anteriorly; the last two or three pairs with a bridge of bone connecting them; but they do not (except in the Naucratinæ) unite in pairs, each pair to form a single hæmal spine.

Epipleurals anteriorly borne by ribs (only so in one genus of Scombridæ).

First interhæmal enlarged (except in the Naucratinæ) and very closely attached to the enlarged first hæmal process.

Caudal rays rather deeply divided, usually not so much so as in the Scombridæ, but more than in the Percoid fishes.

Dorsal spines usually stiff and stout; dorsal and anal finlets sometimes present.

Caudal peduncle slender and the caudal rays divergent.

HYPEROSTOSIS.

Many of the forms of this family have some thickened bones. These are here described away from the main descriptions for better comparison. They are usually dense or ivory-like on the surface, but are more or less cellular inside. Apparently they are a development of age rather than of maturity. That entirely different bones may become thickened in different species of the same genus, or between closely related species, is shown in the two species of *Caranx* here described. It appears further from this material that where the bone thickening occurs at all it occurs consistently in the same bones in individuals of the same species. What individual variation may be expected, or what taxonomic value the character may have, we have not enough material at hand to say. As shown, however, by *Selene* and *Citula*, there may be considerable variation in the size of the thickening, or it may not develop at all in species that normally, or sometimes, have it at a certain age or size. There is no proof with this material that in the latter case, where it has not occurred, it might not have developed with time. The problem should be studied in some locality where a large number of Carangoids of different ages may be examined.

In *Oligoplites mundus*, 18 inches in length, the frontals above the orbital cavity are so thickened that the supraoccipital crest is nearly obliterated. The frontals in this region are nearly $\frac{1}{2}$ inch in thickness. On the lower end of the clavicle is a swollen area $1\frac{1}{2}$ inches

long and $\frac{1}{2}$ inch thick. In a specimen 9 inches long these parts are normal. In *Scomberoides* 12 inches in length no bone thickening has developed. In crania and shoulder girdles of *Seriola* and *Elagatis*, in specimens 3 or 4 feet in length, the bones are normal (the bodies of these specimens are missing). In *Naucrates*, $9\frac{1}{2}$ inches long; *Trachurus*, 15 inches; *Trachurops*, 10 inches; *Decapterus*, 17 inches; *Megalaspis*, 15 inches, and *Chloroscombrus*, 11 inches, the bones are nowhere swollen, though in larger specimens they may occur.

In *Caranx chrysos*, 14 inches long, the only swollen bone is the upper limb of the posttemporal. The distal two-thirds of this bone is so swollen that it forms a heavy round rod on top of the cranium. In *Caranx hippos*, 29 inches in length, there is a great mass of bone in front of the spinous dorsal, and with some of the dorsal rays attached to it, representing one or several united interneurals; it is $2\frac{5}{8}$ inches long, 1 inch wide by 1 inch deep. Three unmodified interneurals occur between it and the occipital crest. In front of the anal fin on the first interhæmal (doubtless representing several interhæmals) is a large knob of bone $1\frac{1}{2}$ inches long, $1\frac{1}{4}$ inches deep, by 1 inch wide. The pelvic girdle is swollen near the middle of its length to about twice its normal thickness, and the interspinous bones at about the middle of the soft dorsal and anal—especially the latter—are swollen. The posttemporal is not swollen.

In *Gnathanodon*, two specimens 20 and 25 inches in length, the interspinous bones of the soft dorsal and anal, except a few anterior ones, are swollen until they are $\frac{1}{2}$ an inch thick in the larger specimens.

In *Selene* almost the entire supraoccipital crest from the frontals backward, and from just above the body of the cranium, is greatly swollen. *S. vomer* and *S. oerstedii* differ from each other, however. In the former the swelling is gradual from the edges of the crest towards the middle, so that the edges are sharp, while in *S. oerstedii* the swelling is abrupt and reaches its full width near the edges of the crest so that the edges are rounded. In *S. vomer*, $16\frac{1}{2}$ inches long, the swollen portion is 2 inches long, $1\frac{3}{4}$ inches deep and $\frac{9}{16}$ of an inch wide. In *S. oerstedii*, 12 inches long, the swelling is of the same proportions, though smaller. In a specimen of *S. vomer*, 5 inches long, the swelling has not yet started.

Several alcoholic specimens of these species were examined and considerable variation found. In two specimens of *S. vomer*, 11 and 12 inches long, the occipital swelling is scarcely indicated, while in two 8 inches long it is developed to a considerable extent, and in a specimen

6 inches long it is just beginning. In a specimen of *S. oerstedii*, 18 inches long, the swelling is exceedingly large, in two 8 inches long it is well developed, and in one 7 inches long it is not yet evident.

In the skeleton of *S. vomer* the lower parts of the clavicle and hypocoracoid are slightly thickened, and the lower end of the post-clavicle is swollen club-shaped. In *S. oerstedii* some of the interspinous bones are very slightly swollen.

In *Vomer setipinnis*, 13½ inches long, there is no occipital swelling whatever. Fourteen alcoholic specimens of this species and of *V. spixii*, from 6 to 12 inches in length, were examined, and they all agree with the skeleton in this respect. In the skeleton the lower part of the hypocoracoids are very much thickened and some of the interspinous rays slightly so.

In a specimen of *Citula dorsalis*, 11 inches in length, there is an abrupt swelling at the upper angle of the supraoccipital crest, so abrupt as to be almost circular in transverse section; it is ¾ of an inch long and ¼ of an inch deep. It is not dense and ivory-like on the surface, as is usual in other forms, but more spongy and cellular. Just behind it the first interneural is swollen to a similar knob, though not so wide. For the occipital swelling several alcoholic specimens were examined. In two specimens, 23 and 11 inches in length, the swelling is as described for the skeleton. In one, 11 inches in length, it covers the same area but is not swollen over half as full, and in one, 10 inches in length, there is no trace of any swelling.

In *Alectis ciliaris*, 14 inches long, only some of the interspinous bones are slightly thickened. Four alcoholics, 8 to 10 inches in length, were examined for an occipital crest swelling, but none was found.

In *Trachinotus* this bone thickening is more marked than in any other form. In the young of *T. carolinus*, 7 inches long (with 4 duplicate skulls), the bones are all normal. In the adult of *T. kennedyi*, 24 inches in length, and the skull of an unknown species, the cranium 4 inches in length, the nasals are much swollen. Each is shaped like an inverted comma (‘) or like a chemist’s glass still. The lower ball-like part is in contact with its opposite fellow, and the arm runs upward and outward to attach it to the cranium. In the largest specimen the ball is ½ an inch across. The preorbital is a heavy dense bone ¾ of an inch thick. The first interneural (or possibly several anchylosed ones) is a large oblong mass of bone slightly overlying the supraoccipital crest, and from its posterior end a ray of bone projects down to the first neural spine. This bone in the large specimen is 2¼ inches long, ½ an inch deep and ⅞ of an inch wide. Between it and the spinous

dorsal there are 2 or 3 supplementary interneurals. It suggests a somewhat similar bone in *Caranx hippos*, but in *Caranx* there is no downward projecting ray of bone, the extra interneurals are in front of it rather than behind it, and no dorsal spines are attached to it. In the large *Trachinotus* the rib of the seventh vertebra is swollen round in section, and is $\frac{3}{4}$ of an inch in diameter. The next preceding one is half as thick, and the next only slightly swollen. The ribs succeeding the seventh are very slender, and not at all swollen. Some of the posterior interspinous rays are somewhat thickened.

The enormously developed pharyngeals, though they are proportionately somewhat larger in the adult than in the young, apparently do not belong to this class of bones; they are large at all ages, while the swollen bones show no indication of increasing size in the young.

OSTEOLOGY.*

Form of Cranium and General Cranial Characters.

The cranium of *Elagatis* is more depressed than any other of these forms, though *Seriola*, *Naucrates* and *Caranx* closely approaches it. In all of these, especially *Seriola* and *Elagatis*, the middle portion of the frontal at each side of the supraoccipital crest is much depressed or sunken far below the level of the anterior and posterior ends. *Megalaspis*, *Trachurus*, *Decapterus* and *Trachurops* follow in about the order named, growing a little deeper in comparison with their width; they all have the region beside the supraoccipital crest somewhat sunken. *Trachinotus*, *Scomberoides* and *Oligoplites* follow in becoming less depressed and in having the frontal region scarcely sunken at the middle. *Chloroscombrus*, *Alectis*, *Citula* and *Gnathanodon* are more compressed than depressed; *Gnathanodon* approaches the shape of *Selene* more nearly in having the upper profile sloping forward and downward toward the vomerine region. And last are *Vomer* and *Selene*, very narrow and deep; the latter triangular in profile, highest at the occiput and sloping steeply to the anterior end.

The myodome is well developed and opens to the exterior at the posterior end through a foramen of varying size, except in *Trachinotus*, where it is reduced to a pore, growing smaller or becoming obsolete in the larger specimens.

There is no auditory swelling or bulla apparent externally.

*See the last end of this paper for a list of species, with their size and locality.

For the accommodation of the more or less divided hyomandibular head there are two depressions on the lower surface of the cranium on each side. The anterior depression is nearly round, and occurs between the preotic and the sphenotic. The posterior one is elliptical and is confined to the pterotic. There is no indication of the depression on the under side of the cranium, which in some genera of the Scombridae excludes the pterotic from the brain cavity.

The supraoccipital crest is always well developed and rises in a thin, high, blade-like crest, extending nearly the whole length of the cranium, and reaching forward in all cases to the ethmoid. The crest is formed anteriorly by the frontals. Above the frontals its base is always expanded and thicker than above the supraoccipital. Posteriorly the crest extends behind the epiotics to above the occipital condyle, where it is usually the highest.

The temporal crest is always thin and high, and is formed by the epiotic, the parietal and the frontal. In nearly all genera it reaches the edge of the cranium a little in front of the middle of the orbital cavity. In *Citula* and *Oligoplites* the crest ends more posteriorly than in any of the others, and in the latter scarcely reaches the cranial edge (see under pterotic crest). In *Trachinotus* the crest does not typically reach the edge at all, but runs nearly straight forward to the front of the frontal, where it ends considerably inward from the edge of the cranium. This, however, is apparently not a stable character, as in some of the young examples the crest on one or both sides is deflected towards the edge and is then not different from the usual arrangement. In *Oligoplites* the crest is produced to a slight spur on the parietal and dips low on the epiotic and frontal. In *Scomberoides* the crest is high throughout, as in the other forms.

The pterotic crest in most of the genera reaches the edge of the cranium just behind the anterior ending of the temporal crest. In *Decapterus*, *Trachurops* and *Trachurus* it ends farther back than in the others, or over the posterior end of the orbital cavity at a considerable distance behind the temporal crest. *Citula* differs from the others in having the pterotic crest united with the temporal at a considerable distance behind the anterior end of the latter. In *Oligoplites* the temporal and pterotic crests come together and sink into the level of the frontal over the posterior edge of the orbital cavity much as they do in *Scomber*. From this union only the slightest indication of a ridge runs laterally to the cranial edge.

Posteriorly the pterotic crest ends in a more or less well developed secondary spine at the base of the backward projecting pterotic spine.

The crest carries a series of sensory tubes, which radiate outward from its base to its edge. A sharp, high, superorbital rim is always distinct, curving downward behind and below the pterotic crest.

CRANIAL ELEMENTS.

The exoccipitals are in contact with each other for their full length along their upper edges, but as the supraoccipital overlies the suture between them they appear on the surface of the cranium to be separated by the latter bone. They are also in contact along their lower edges over the basioccipital, though in the small specimens of *Trachinotus*, and in *Decapterus*, they fail to meet at the mouth of the foramen magnum. In the large specimen of *Trachinotus*, however, they meet broadly in this region (the small and large specimens being of different species, this may be either a variation of species or of age). The articular facets of the exoccipital condyles are not always contiguous above the basioccipital, even when the exoccipitals are in contact just in front of them. In *Trachurus*, *Trachurops*, *Megalaspis*, *Naucrates*, *Oligoplites* and *Decapterus* they are separated. In the others they meet more or less broadly. In the fusiform genera the exoccipital condyles slope over the basioccipital condyle in a normal degree, but in the deep compressed genera the former overhang the latter so much that their slope towards each other forms a right angle. *Decapterus* is peculiar in having the exoccipital condyles at the side and wholly below the level of the upper edge of the basioccipital, while their posterior surface is a little anterior to that of the basioccipital condyle.

The supraoccipital is developed very far forward in the crest, extending in most cases to above the middle of the orbital cavity, but in *Trachinotus* it extends to above the front of the orbital cavity, or nearly the whole length of the frontals. In this genus the length of the supraoccipital equals three-quarters of the length of the entire cranium. Between these two conditions are all intermediate gradations.

As viewed from the outside of the cranium the epiotics appear on each side of the supraoccipital widely separated, but from the inside their condition is various. In *Oligoplites* and *Scomberoides* the epiotics meet for their full length at the median line, and the supraoccipital can not be said to separate them in any degree. In *Caranx* they are joined for about half of their length, while the supraoccipital separates them above. In *Megalaspis* and *Chloroscombrus* they only narrowly meet. In the others a wedge of the supraoccipital extends downward between them, below which an area of cartilage separates them more or less widely.

The opisthotic separates the exoccipital from the pterotic to a varying extent, or not at all, but in no case is it interposed to so great a degree as in most of the family Scombridae. Usually the condition of this bone does not differ from that of the Percoid fishes; i. e., the opisthotic is chiefly on the lower surface of the skull covering the exoccipital-pterotic suture, so that superficially, as viewed from below, the exoccipital seems to be widely separated from the pterotic. As viewed from above a very small portion of the opisthotic shows just behind the exoccipital-pterotic suture. Often there is a shallow notch at the end of this suture in which the opisthotic appears, but to so small an extent that the opisthotic can scarcely be said to separate the exoccipital from the pterotic in any degree. The notch as viewed from above is a little deeper in *Oligoplites*, *Scomberoides*, *Alectis*, *Citula*, *Gnathanodon* and *Megalaspis* than in the other genera, and in *Trachinotus* it is very much deeper, separating to a considerable extent the exoccipital from the pterotic, approaching nearer the condition of the Scombridae than any of the others do.

In *Oligoplites* and *Scomberoides* the lower posttemporal limb is attached to the upper surface of the opisthotic, as it is in most of the members of the family Scomberidae. In the others it varies from this condition to that of having the lower limb attached more or less to the posterior edge, as in the Percoids.*

In *Gnathanodon* the anterior part of the pterotic incloses a very large foramen, at least two-thirds as wide as the pterotic crest. This is developed to a smaller degree in *Decapterus* and *Trachurus*; in all of the others it is entirely absent.

The basisphenoid is present and has a well developed process descending to the parasphenoid, where it is rather broadly attached. There is always a foramen just behind it, in front of the prootic suture, and opening into the myodome.

The alisphenoids are in all cases widely separated by the anterior opening to the brain case. A pair of wings or ridges on the lower surface of the frontals are continuous with the alisphenoid edges. They converge forward except in *Trachinotus*, where they run straight and nearly parallel to the prefrontals.

The parietals are always well developed and form the middle portion of the temporal crest. They are always widely separated by the supraoccipital.

*The distinction between posterior upper surface and posterior edge is not great, and as it is somewhat variable, its importance is of questionable value. *Scomber* is nearer to the Percoids in this respect than it is to the other genera of its family, or to most of the Carangoids.

Though the supraoccipital widely covers the greater part of the suture between the frontals, they meet below it for their full length. They form the anterior part of the supraoccipital crest, carrying it to the ethmoid. In this portion of the crest, especially when the crest is thin, there is often no trace of a suture between the frontals. The suture is, however, always evident on the lower surface of the frontals within the orbital cavity, and in a fresh or well macerated specimen the frontals may be separated through the crest.

No portion of the ethmoid shows in the orbital cavity between the prefrontals except in *Chloroscombrus*, where a very small portion of it shows in this region at the upper part of the prefrontal suture.

In *Seriola* the ethmoid is very broad, and for convenience may be described as consisting of two portions. The superior portion is a broad plate, concave in front, and directly from under it medially a blunt keel on the inferior portion projects downward and forward. *Megalaspis*, *Elagatis*, *Oligoplites*, *Scomberoides* and *Naucrates* are essentially the same, but in the last three the inferior portion is sharper in front and descends more abruptly, not projecting much forward. In *Gnathanodon*, *Citula*, *Trachurops*, *Chloroscombrus* and *Caranx*, the superior portion is concave in front, but very narrow (only slightly so in *Caranx*), and just below it is a cup-shaped depression replacing the keel, which is only developed at the lower end near the vomer remote from the superior portion. *Decapterus* is somewhat between these two conditions; the superior portion is very narrow, with only an indication of a concave front, and the keel of the lower portion, though not in intimate relation with the superior portion, is not separated from it by a depression. In *Trachinotus* and *Alectis* the superior portion is produced, moderately narrow, convex in front, and with a keel about as in *Decapterus*. *Trachurus*, *Selene* and *Vomer* are of the same type as the last, but with the superior portion scarcely, or not at all, widened. These conditions, though marked in the extremes, merge more or less with each other.

The prefrontals meet broadly behind the ethmoid in front of the orbital cavity. They are pierced by the olfactory nerve. Usually they form a broad outstanding mass on each side, angulated below and having an articular surface on their lower edge for the palatine, but in *Selene* they are gently rounded in outline, and ascend nearly straight to the frontals without an angle. On the anterior surface of each prefrontal at the side of the ethmoid, and often assisted by the latter, a cavity is formed in many examples. In *Elagatis* the cavity is particularly shallow, but very wide and long. The frontal reaches far over it,

forming a roof, and the ethmoid forms a septum opposite fellow, though behind the ethmoid there is a passage, which in the fresh fish was probably filled with mucus. The olfactory foramen enters this chamber at its outer end. In *Naucrates* there is only a trace of this chamber. It is well developed in *Gnathanodon*, but is lower on the frontal forms no part of its roof, though the ethmoid forms part of it. It is in this form much deeper than downward to the parasphenoid. The olfactory foramen is at the posterior end of it. It is similar to *Gnathanodon*, but considerably smaller. It is moderately developed in *Trachurus*, *Trachuroops* and *Decapterus*; but the foramen is so far to its outer edge that it cannot enter it. In *Chloroscombrus*, *Vomer* and *Selene* it is opened, and in *Trachynotus*, *Caranx*, *Oligoplites* and not present at all.

The vomer bears a keel on its upper surface, continuation of the ethmoid keel. At each side of the keel is a premaxillary process.

The parasphenoid is sharply keeled under the mouth of the myodome it sends a lateral wing of the prootic, but it is confined to that bone, never alisphenoid or sphenotic. *Trachynotus* differs from *Gnathanodon* in having the parasphenoid expanded to two or three times its normal width to form a broad, flat table, against which the enlarged superior pharyngeals lie. This expansion is in the prootic, which is developed outward to the ethmoid, or a little beyond. *Gnathanodon* differs from *Trachynotus* in having a protuberance on the parasphenoid under which contains a conical cavity with its apex pointing straight forward. This is doubtless the homolog of a somewhat similar cavity in the division of the Scombridae, into which the posterior nostril enters. In *Gnathanodon*, however, it is farther from the foramen.

Other cranial elements not mentioned do not differ appreciable extent from the majority of spiny-rayed fishes.

The Lateral Head Bones.

The lateral bones of the head do not differ materially from those of the family Scombridae. The bones of the suspensorium are fused together, and there are usually no openings between them.

The opercular bones do not in general form such broad, smooth areas as in the Scombridæ. There are no preopercular serrations except in the very young, and there is never an open sensory canal along the preopercular ridge. When there is any indication of a sensory system in the bone in this region it is in the form of very fine tubes. *Trachurus* is somewhat of an exception to this in having much larger tubes than in any of the other genera.

The head of the hyomandibular, where it articulates with the cranium, is more or less divided into two parts. In *Gnathanodon* the parts are contiguous, or with only a slight notch between them. In *Elagatis* they are remote from each other. Between these two degrees of separation there are all intermediate conditions, though they are usually at least slightly separated. The hyomandibular is channeled behind to receive the preopercle, and sends back a process to support the opercle. In *Oligoplites* the upper end of the hyomandibular bears on its outer surface a large wing of bone, pointing forward as in *Caranx hippos* (see under suborbitals), but there is no stay from the suborbital ring attached to it. In *Scomberoides* this process is reduced to a small, inconspicuous point.

There is never any opening between the hyomandibular and metapterygoid that frequently appears in Percoid fishes except in *Gnathanodon*, and to a slight extent *Trachurus*. The condition in the former genus is identical with that of *Roccus*. The metapterygoid throws out a broad wing, which extends backward to near the preopercular ridge, leaving a wide, open space behind it. In *Trachurus* the wing is feebly developed, and it fits so closely against the hyomandibular that the open space is scarcely apparent. No trace of it is apparent in any of the others.

The mesopterygoid forms a broad supporting shelf for the orbit.

The symplectic extends for a considerable distance behind the quadrate in a channel.

Usually the pterygoid turns at a right angle and reaches forward towards the prefrontal, as it does in the majority of fishes. The anterior end of the pterygoid, and often a small part of the posterior end of the palatine is attached to the prefrontal. Often a small tubercle of bone is developed on the pterygoid just behind this attachment. But as the cranium becomes flexed downward and the face bones drawn forward, as in some of the deep, compressed forms, the pterygoid is directed nearly straight upward and finally even somewhat backward, while the tubercle of bone becomes a long spur or process extending

behind the prefrontal. *Gnathodon* and *Chloroscombrus* show a marked inclination towards this condition. The pterygoid is developed nearly straight upward, and the process behind the prefrontal is long. In *Alectis* and *Citula* the pterygoid is bent farther back, and the process is longer, while in *Vomer* and *Selene* it is bent very decidedly back, the process is still longer, and serves as the only attachment of the pterygoid to the prefrontal.

The palatine is attached more or less firmly, and with or without a differentiated articular surface, to the front of the prefrontal. The anterior end bears a strong process, which hooks over the maxillary.

The angular is well developed. In *Oligoplites* and *Vomer* the articular completely fills the V-shaped space between the backward extending arms of the dentary. In *Scomberoides* a small space is unfilled above. In *Naucrates* and *Elagatis* a considerable space is unfilled, and in the others the upper arm of the dentary and the upper edge of the articular are only in contact at a small place anteriorly.

In *Oligoplites* the dentary is peculiar in having a free wing of bone on the inside, running forward nearly to the symphysis. This wing is present in nearly all other bony fishes, but it curves downward and becomes absorbed near the middle of the mandible. In *Scomberoides* this free wing does not run far forward, but from below its lower edge a second wing is developed, which folds downward and runs back to the posterior end of the lower limb of the dentary, keeping considerably above the lower edge of the dentary for its full length.

In *Oligoplites* and *Scomberoides* the maxillary and premaxillary elements are long and slender, and rather closely attached to each other. The premaxillary sends no sharp spur behind the maxillary, though a long inner fold of bone clasps the latter rather closely. A supplementary maxillary is not present in *Oligoplites*, but in *Scomberoides* it is developed, though rather small as compared with those of the other Carangoids. In *Trachinotus* the maxillary elements are short and loosely attached to each other; the maxillary spur behind the premaxillary is little developed; and the supplementary maxillary is absent. In all of the other forms the maxillary elements are very wide, particularly the posterior end of the maxillary; rather loosely attached to each other, especially in those forms with long premaxillary processes; they bear upon their upper edges very large supplementary maxillaries, and from the middle of the premaxillary a large triangular spur is sent behind the maxillary.

The ascending processes of the premaxillaries are very short and triangular in *Oligoplites*, *Scomberoides*, *Elagatis* and *Naucrates*. In

Decapterus, *Megalaspis*, *Caranx*, *Trachurus*, *Trachurops* and *Chloroscombrus* they are longer, while in the rest, *Gnathanodon*, *Alectis*, *Citula*, *Vomer* and *Selene*, they are very long.

The nasals are attached to the frontals and ethmoid and project forward. They are never nonprojecting and attached for their full length to the frontal and ethmoid, as in some genera of the family Scombridae. They are close together or wide apart, according to whether the ethmoid is wide or narrow, so their variation in this respect is indicated by the description of the ethmoid. In *Trachurus*, which has the thinnest ethmoid, the nasals are almost in contact at their bases.

The suborbital chain of bones is always complete and carries a sensory tube. In *Caranx hippos* a wide process is sent from the last suborbital that is on the lower level of the eye (apparently the third suborbital) upward and backward across the cheek to the upper end of the hyomandibular, where it is attached to a broad, thin wing of bone, which bends forward to receive it from just in front of the upper end of the preopercle. The upper suborbitals send back a wide, thin plate, which partly covers this stay. In *Caranx chrysos* the stay is only a little developed. It ends in a free point, and there is no process developed from the hyomandibular to meet it. In *Oligoplites* the lower and posterior suborbitals are spread out into thin laminae, which, running backwards, covers a large part of the cheek. The lower edge of this is developed from the lower level of the eye, and extends downward and backward along the maxillary nearly to the ridge of the quadrate, which is a continuation of the preopercular ridge. There is no indication of a stay in any of the other forms.*

The suborbital shelf is in various conditions (see footnote under diagnosis of characters). In some forms it is well developed, in others it is slightly indicated or absent. In *Oligoplites* and some species of *Trachynotus* it is absent. In *Vomer* it is only slightly indicated, and between this condition and a well developed shelf there are all gradations.

The eye has a bony sclerotic case, never so complete or never so dense and thick as in the Scombridae, and often no better developed than in many Percoid fishes.

*The condition of the suborbital bones in *Caranx* and *Oligoplites* suggests the suborbital stay of the mail-cheek fishes. Though in one genus it extends upward across the cheek and in the other downward it springs in each of them from the last suborbital on the lower level of the eye just as it does in the mail-cheek fishes. In this connection it of course signifies nothing, being doubtless a case of parallel development.

The Branchial and Hyoid Arches.

There are three tooth-bearing superior pharyngeals on each side of the last three arches, and a styliform naked one on the first arch in all of the forms here considered. The first toothed pharyngeal is elongate and lies in front and along the outer edge of the second. The second is always the largest; the third is directly behind it and rather closely joined to it, so that they together form an elliptical plate. The teeth on both the superior and inferior pharyngeals of *Elagatis*, *Oligoplites* and *Naucrates* are fine and sharp. In the others some, or nearly all, of the teeth are blunt molar teeth, particularly on the second toothed superior pharyngeal and along the middle of the inferior pharyngeal.

The inferior pharyngeals lie close together along their inner edges for the greater part of their length and widely diverge posteriorly. In *Elagatis*, *Naucrates*, *Scomberoides* and *Oligoplites* they are less closely attached than in the others.

Trachinotus is an exception to all of the foregoing pharyngeal characters. In this genus the pharyngeals are developed to a remarkable size. In the largest skeleton (*T. kennedyi*, 24 inches long) the first toothed pharyngeal is so reduced as to be practically functionless; it is $\frac{1}{4}$ of an inch wide and half as long. The second is greatly enlarged, being $1\frac{5}{8}$ inches long by half as wide, and $\frac{3}{4}$ of an inch thick. The third is $\frac{7}{16}$ of an inch wide by $\frac{3}{16}$ of an inch long. Each inferior pharyngeal is 2 inches long by half as wide and $\frac{3}{4}$ of an inch thick. The first superior pharyngeal lies at the outer side of the second, considerably behind its front end, while the third is at the posterior end of the second and does not enter into its outline as in the other forms. The inferior pharyngeals and the second toothed pharyngeals of opposite sides meet at the median line and are closely joined to each other, each pair forming an equilaterally triangular plate, so closely joined as to form an almost unbroken surface from side to side. In the superior pharyngeals the triangular shape is less evident, as the outer angles are broadly rounded. The inferior plate is shallowly concave, and the superior correspondingly convex. Except at the anterior end the plates are covered with a smooth pavement, as if the bone, or close-set teeth, had been ground down to a common level. The anterior parts are deeply pitted.

In the young the tooth plates are scarcely so thick correspondingly, and they are pitted all over the grinding surfaces. These bones are apparently not of the same character as the bones that thicken or swell

with age. They are large in all ages, and the base of the skull is expanded to accommodate them.

Three basibranchials are present in all genera, the first in front of the hypobranchials of the first arch and hooking under the glossohyal, as in the family Scombridæ. The hypobranchials of the fourth arch are missing, as they almost universally are in bony fishes.

There is nothing remarkable about the hyoid arch. All of the usual elements are present: a glossohyal and urohyal, two hypohyals on each side and a cerato, epi and interhyal. The urohyal bears a longitudinal wing of bone along its lower edge on each side, and the ceratohyal is pierced by a large foramen near its upper edge.

The Shoulder and Pelvic Girdles.

The shoulder girdle shows scarcely any departure from the typical acanthopteroïd arrangement. The pectoral is not placed so near the level of the top of the clavicle as in the Scombridæ, and the clavicle does not slope so far forward below it, being more nearly vertical. *Elagatis*, *Seriola*, *Naucrates*, *Oligoplites* and *Scomberoides* approach the condition of the Scombridæ in this respect more nearly than the others do, though not very nearly. The clavicle ends above in a point, over which the supraclavicle articulates. Below the point and just above the actinosts a broad, rounded wing is sent back for the support of the postclavicle.

The postclavicle is in two parts, an upper wide, thin bone and a lower long, narrow bone, sometimes long and slender like a typical fish rib.

A large foramen is entirely contained by the hypercoracoid, but either the clavicle or the hypocoracoid may send a lamina of bone to its border on the outer surface of the girdle.

The suture between the hypo and hypercoracoids usually ends between the third and fourth actinosts from the top, but it may vary from the middle of the third to the middle of the fourth, so that $2\frac{1}{2}$ to $3\frac{1}{2}$ of the 4 actinosts are supported by the hypercoracoid.

The hypocoracoid arches away from the clavicle and nearly, or quite, meets it again at its lower end. The clavicle never projects far beyond the lower end of the hypocoracoid as in many of the Scombridæ.

A large supraclavicle is always present. The posttemporal is widely forked except in *Trachinotus*. The upper fork broadly overlies the epiotic, and is a little more firmly attached than is usual. It often

extends to, or very slightly encroaches upon, the supraoccipital or the parietal. The lower limb of the posttemporal is attached directly to the opisthotic without the intervention of a ligament. In *Trachinotus* the posttemporal is scarcely forked at all. Its lower end is very wide and its lower fork is exceedingly thick and heavy, being but little produced beyond the general outline of the bone. It forms an unusually broad union with the opisthotic.

The pelvic girdle is in no way notable. Each side rises along its inner edge at the median line to form a low ridge, while at the outer edge each side turns downward and is divided into two longitudinal wings, with often a more or less evident third wing between. At the posterior union of the sides a spine-like process is sent forward below from the base of the ventrals, and above a forked process is sent backward over the base of the ventrals.

The Vertebral Column, Ribs, and Fin Elements.

The number of the abdominal vertebræ in all of the forms here considered is 10. The number of the caudal vertebræ is 14 in all but *Naucrates* and *Caranx chrysos*, which have 15 (though *Caranx hippos* has 14), and in *Oligoplites* and *Scomberoides*, which have 16.

The parapophyses are not developed very far forward. From three to five are usually present, though one or two undeveloped ones may be present in front of these in some forms (they appear so gradually it is difficult to be exact as to the number of developed ones). The last two or three (in *Alectis* one) of them are connected with their opposite fellows by a bridge of bone, leaving a hæmal canal above, and their points projecting separately below. The first hæmal process is differentiated from the last connected parapophyses by being single pointed and much longer and stronger, so that the vertebral column is sharply divided into an abdominal and caudal portion, aside from the indication of this division by the attachment of ribs and anal fin.

Seriola and *Naucrates* are exceptions to these rules. These forms approach the Scombridæ in having the posterior pair of parapophyses united into a single spine, with the ribs at its tip, and the first hæmal process not abruptly enlarged or otherwise differentiated from it. *Decapterus* approaches this condition in having the last pair of parapophyses united into a rounded arch, but with scarcely a spine developed, the ribs not in contact, and the first hæmal process considerably enlarged.

The zygopophyses are usually very large and resemble those of the Scombridæ. On the upper surface of the front of each vertebra a flat

process at each side of the neural canal extends upward and forward, while just below it and separated from it by a notch is a small spine or spur directed forward. On the posterior end of each vertebra a similar spur is directed backward and fits into the notch of the succeeding vertebra. At each end of the lower surface of each vertebra is an inferior zygapophysis; the anterior one projecting over the posterior one of the next preceding vertebra. These are larger in *Megalaspis* than in the others.

In *Megalaspis* the neural and hæmal spines of the tail region become flattened and lie flat each against the surface of the next succeeding vertebra, restricting its movement to a lateral one. From the upper and lower surface of each caudal peduncle vertebra a sharp longitudinal wing is developed laterally, and from the side of each of the 5 or 6 vertebræ preceding the third in front of the caudal a flat spine is produced, forming a broken caudal keel. The caudal fin rays are very deeply cleft at the base, and so broadly clasp the hypural bone as to nearly hide it from sight. *Caranx* approaches this condition, and to a less degree *Trachurops*, *Trachurus* and *Decapterus*. In *Megalaspis* the inferior vertebral foramina are greatly enlarged. These attain their greatest size in the bases of the last parapophyses, where the largest is equal in diameter to the least width of the vertebral centrum just above it. *Caranx*, *Chloroscombrus* and *Gnathanodon* show this condition to a less degree; *Citula*, *Alectis* and *Vomer* have the inferior foramina more or less developed in the bases of the hæmal arches and parapophyses, while in *Decapterus*, *Trachurops*, *Trachurus* and *Selene* the foramina are confined to the hæmal arches.

With the exception of *Seriola* and *Naucrates* and to a much less degree *Trachurops*, *Trachurus* and *Decapterus* the first interhæmal is very large and strong, and is very solidly attached to the equally strong first hæmal process. Often this stay is further reinforced behind by other interhæmal bones, which incline forward against it.

The interspinous rays of the dorsal spines about coincide in number with the neural processes, but those of the dorsal and anal rays are two or three to one of the neural and hæmal processes.

The first two vertebræ bear epipleurals only. The other anterior epipleurals are always on the ribs. The anterior ribs are attached directly to the vertebral centra, sometimes, as in *Trachurops*, *Caranx* and *Decapterus*, in deep pits, whose edges are raised above the body of the centra. *Scomberoides* and *Oligoplites* are peculiar in having the ribs attached high on the centra, remote from the parapophyses, except the posterior two pairs, which drop down to the tips of the parapophyses.

MATERIAL.

This paper is based upon the following genera and species:

Oligoplites.

A specimen of *O. mundus*, 18 inches in length, and a cranium of the same species of a specimen 9 inches in length; both from Panama.

Scomberoides.

A specimen of *S. toloparah*, 12 inches in length, from the Philippine Islands.

Elagatis.

A head and shoulder-girdle of a specimen of *E. bipinnulatus*, 31 inches in length, from the Galapagos Islands.

Naucrates.

A specimen of *N. ductor*, 9½ inches in length, from Japan.

Seriola.

A cranium and shoulder-girdle of *S. dorsalis*, of a specimen 3 or 4 feet in length, from San Diego; the cranium 5½ inches long; the vertebral characters described from an alcoholic specimen of *S. zonata*, opened along the vertebral column.

Decapterus.

A specimen of *D. punctatus*, 17 inches in length, from Florida.

Trachurops.

A specimen of *T. crumenophthalmus*, 10 inches in length, from Cuba.

Trachurus.

A specimen of *T. mediterraneus*, 15 inches in length, from the Canary Islands.

Caranx.

A specimen of *C. chrysos*, 14 inches in length, from Cuba, and one of *C. hippos*, 29 inches in length, from the Pacific Coast of Mexico.

Megalaspis.

A specimen of *M. cordyla*, 15 inches in length, from Formosa.

Gnathanodon.

Two specimens of *G. speciosus*, 20 and 25 inches in length, from the Pacific Coast of Central America.

Citula.

A specimen of *C. dorsalis*, 11 inches in length, from Panama.

Alectis.

A specimen of *A. ciliaris*, 14 inches in length, from Cuba.

Chloroscombrus.

A specimen of *C. chrysurus*, 11 inches in length, from Florida.

Vomer.

A specimen of *V. setipinnis*, 13½ inches in length, from Panama.

Selene.

A specimen of *S. vomer*, 16½ inches in length, from Mazatlan, Mexico; one of the same species 5 inches in length, from Maryland, and a specimen of *S. oerstedii*, 12 inches in length, from Panama.

Trachinotus.

A specimen of *T. kennedyi*, 24 inches in length, from Panama; one of *T. carolinus* (with 4 duplicate crania), 7 inches in length, from Maryland, and a head with the locality and species unknown, the cranium 4 inches in length.

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No. 6

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BY

FERNANDO SANFORD

Professor of Physics

WITH TWO PLATES AND ELEVEN TEXT FIGURES

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1. The first part of the document is a list of names and addresses of the members of the committee.

TABLE OF CONTENTS.

	PAGE
INTRODUCTION	5
Elements of the Theory.	
ELECTROSTATIC PHENOMENA.....	11
Electric Repulsion and Attraction.	
Electrical Induction.	
The Electrical Condenser.	
The Hollow Conductor.	
Electric Density and Surface Curvature.	
Surface Curvature and Induction.	
Metallic Conductivity.	
Contact Electromotive Force.	
Cohesion.	
ELECTRIC CURRENTS	47
Electrolysis.	
The Voltaic Cell.	
Charges of Electrolytic Ions.	
ATOMIC CHARGES	55
Positive Charges of Ions from Hot Metals.	
Charges of Monatomic Gas Molecules.	
Atomic Charges and Solubility.	
Charges of Atomic Ions in Flames.	
Atomic Charges and Chemical Valence.	
ELECTROMAGNETIC PHENOMENA	64
The Electromagnetic Field.	
Magnetism in Iron.	
APPENDIX	67
Note on the Electrical Theory of Benjamin Franklin.	
PLATE I.	
Atomic Charges and Square Roots of Atomic Weights.	
PLATE II.	
Solubilities and Square Roots of Atomic Weights.	

1. The first part of the document is a list of names and dates.

Atomic Charges and Square Roots of Atomic Weights.

H	Li			
1	2.5			
11	9.			
F	Na.	Mg		
4.4	4.8	4.9		
31.	36.	30.		
Cl	K	Ca		
6.	6.2	6.3		
80.	88.	79.	Ni	Cu
			7.6	8.—
Br	Rb	Sr	130.	146.
9.	9.25	9.4		
188.	202.	176.	Pd	Ag
			10.3	10.4
I	Cs	Ba	225.	232.
11.3	11.5	11.7		
293.	314.	280.	?	?
			Pt	Au
			14.—	14.+
			471	546.& 273

This relation is shown more strikingly in Curve I, Plate I, where the atomic charges calculated by the two methods are plotted as abscissas and the square roots of the atomic weights as ordinates. It will be seen that the agreement of the values calculated by the two methods is very close except in the case of gold, where one of Richardson's values lies on each side of the expected value, and of platinum. Strictly speaking, the elements of each group lie on a curve of their own,* but these group curves are parallel and very close together.

*It should be remembered in this connection that the charges of the halogen group were calculated from the velocities of negative ions. They should properly be represented on a branch curve for which the values of the atomic charges are negative. This curve would be perfectly symmetrical with the curve given.

It is sometimes suggested by Hertzmann and Finkner for values of α as low as 100 that the value of α is 1. It follows that positive and negative charges are separated by distances which are directly proportional to the square roots of their atomic weights. It also seems to follow that the ions in electrolytes move with approximately constant velocity through the small distances between condensation and recombination.

Charges of Monatomic Gas Molecules.

A method which may be used for estimating at least roughly, the charges of gas molecules is found in the assumption that cohesion must be in some approximately proportion to the molecular charges. In a paper by V. Sutherland² on the *Viscosity of Gases and Molecular Forces* is given a method of calculating the cohesion between gas molecules from the viscosity of the gases and the laws of the kinetic gas theory. Lennard-Jones has recently measured the viscosity of the gases of the Argon group and has calculated from his data and Sutherland's equation the magnitude of Sutherland's cohesion factor C for these gases. His values are as follows: Helium, 71; Neon, 54; Argon, 142; Krypton, 166; Xenon, 352. He calls attention to the evident mistake of Lennard-Jones in this work, since from its low critical temperature it should have much less cohesion than any of the other gases. He finds in the case of the other gases that the ratio of the critical temperature absolute to the cohesion factor is about 1:22. By calculating C from this ratio for Helium it is found to have a value of about three instead of seventy.

If it be assumed that cohesion is proportional to the atomic charge in these monatomic molecules, then the factor C should be proportional to the square roots of the atomic weights, which it is within the limits of experimental error:

Atomic Charges and Solubility.

A similar relation between the same gases is shown in their solubility in water. A. v. Antropoff³ has determined the

²Sutherland, Phil. Mag., xxxvi, 50, 1893.

³Pankine, Physik. Zeitsch., xi, 746, Sept., 1910.

⁴Since this paper was in the hands of the printer I find an article by Rankine in the Phil. Mag. of Jan., 1911, p. 45, in which he also relates the viscosities of the gases of the Argon group to the square roots of their atomic weights.

⁵v. Antropoff, Roy. Soc. Proc., A, lxxxiii, 474, Apr. 14, 1910.

solubility of the above gases in water at different temperatures. For 20 degrees his numbers are as follows: He, .0138; Ne, .0147; Ar, .0379; Kr, .0729; Xe, .1109. The relation between this solubility factor and Sutherland's cohesion factor is apparent at a glance. This is to be expected, since the solubility should be a measure of the cohesion between the gas molecules and water. It will be seen that these solubility factors are also, within the limits of experimental error, proportional to the square roots of the atomic weights, helium, as before, being an exception.

In Curve II, Plate II, the values of Sutherland's cohesion factor as calculated by Rankine and the values of v. Antropoff's solubility factors are plotted as abscissas against the square roots of the atomic weights as ordinates. The solubility factors have been multiplied by the constant 3×10^4 to bring them on the same diagram as the other factors. The points for the cohesion factors are represented by large circles and for the solubility factors by small, black circles. The curve is drawn for v. Antropoff's solubility factors. Helium is seen to depart from the law in the same manner in both cases. If its cohesion factor be used as calculated by Rankine from its critical temperature, it falls directly upon the curve for this factor.

It will be seen that the curve drawn cuts the axis of ordinates at nearly the same point as does Curve I. Accordingly the atomic charges of the elements may be calculated from either curve by using the equation $e = (\sqrt{w} - a) k$, where w is the atomic weight and a is a constant between three and four. The same equation with approximately the same constant may be used to calculate the values of Sutherland's cohesion factor.

The above relations seem to the writer to make the conclusion inevitable that gaseous solubility in water is proportional to the cohesion of the gas molecules for the water molecules, and that this cohesion is proportional to the atomic charges, when the gases are monatomic. In the case of gases having compound molecules the same law would probably hold except that the cohesion would be proportional to the residual molecular charge. Hence gases having high critical temperatures should be more soluble than gases having low critical temperatures.

It is interesting in this connection to note that Traube* and Kleeman† have calculated that the valency of an atom is proportional to the square root of its atomic weight. In the paper referred to, Kleeman

*Traube, Physick. Zeitsch., x, 667, Oct., 1909.

†Kleeman, Phil. Mag., xix, 784, May, 1910.

According to this if a number of atoms of a substance are united together in a definite manner it is the number of atoms of which the atoms are. This constant depends not only on the nature of the atoms but also on the position of the atoms in the molecule. This would seem to make constant values as well as constant very difficult to be found.

Changes in Atomic Weights in Groups

A constant relationship to the character of ions in most bodies may be found in the observation of some metallic salts in a form. When salts of the same metals are considered in a different form, the number of the same is changed by the nature of the ions. In 1871 Irving has shown that when the ions are well separated from the other part of the salt, they sometimes are strongly attracted toward the negative side of an electric field showing distinctly the electropositive character of the ions which give the color to the salt. Irving determined the order of the positive attraction of the ions of different metals in a given electrostatic field. In the case of the ions of the alkali group, which were most readily to be separated into positive and negative ions, he found the order of attraction to be sodium, potassium, lithium, rubidium. In this experiment, where the ions were most certainly

Since this paper was ready for the printer I have been able to calculate the compressibilities of a large number of elements from the formula $\alpha = \frac{1}{\rho} \frac{d\rho}{dT}$ & the constants α and ρ varying from group to group though for several groups α has a value of approximately 1. In the electropositive elements the equation takes the form $\alpha = \frac{1}{\rho} \frac{d\rho}{dT}$ & thus as the compressibility increases as the negative charge of the element increases. This would be expected from the fact already mentioned that the more electropositive a metal is in the periodic series the greater is its cohesion.

I have also been able to calculate the approximate melting points of a broad range number of elements from simple formulae in which the square root of the atomic weight is the factor. Thus the approximate melting point of the alkali metals may be calculated from the formula $T = \frac{1}{\sqrt{W}}$, $\alpha = 2$ where T is the melting point (centigrade), of the element and α and ρ are constants for the group. If $\alpha = 2.15$ and $\rho = 0.115$ the calculated values of the melting points will vary on the average only 2% from the experimental values.

The atomic refraction as calculated by Edwards (Am. Chem. Jour., vols. 16 and 17), and by Fawcett (Zem. phys. Chem. LXXV, 585, Dec., 1910), also varies as the square root of the atomic weights of the elements. No doubt this constant will be found to be an important factor in calculating many other properties of the elements.

Irving, Phys. Rev., xxix, 248, 1909.

the positive sub-atoms of the metals with all possibility of hydration excluded, the order of deflection is that indicated by the atomic charges of the metals as calculated above, and is the inverse of what it should be if the ions carried equal charges.

The same order also holds in the conductivities of the metallic vapors of this group. The conductivities of flames containing vapors of the metals of this group are given as follows: Caesium, 116; rubidium, 82; potassium, 64; sodium, 8.5; lithium, 2.5.

Atomic Charges and Chemical Valence.

Further arguments against the equality of sub-atomic charges may be found in the phenomena of chemical valence. The writer of this paper, not being a chemist, approaches this part of the argument with a full appreciation of his liability to err from lack of familiarity with the phenomena under consideration. In order to make this liability as small as possible, the discussion will be confined to a few of the phenomena of chemical valence which were quoted by Richard Abegg in his celebrated paper entitled *Die Valenz und das periodische System*.^{*} This selection of phenomena seems all the more suitable for the reason that it was made for the purpose of substantiating an entirely different theory of chemical valence.

As has already been stated several times, the point of view of this paper is that all molecules are made up of electropositive sub-atoms held together by their mutual attractions for the same electron or group of electrons. When a molecule dissociates, the more positive sub-atom holds an excess of the connecting electrons and becomes the negative ion. Thus the hydrochloric acid molecule is presumably made up of two sub-atoms, one of hydrogen and one of chlorine, held together by their mutual attraction for one or more detachable electrons. When they dissociate the chlorine always takes the connecting electron or excess of electrons, if there be more than one, hence it must be the more positive sub-atom; otherwise the attraction between it and the electron would be less than the attraction between the hydrogen sub-atom and the electron.

In the following discussion the propositions regarding valence which are italicised are quoted from Abegg's paper.

All atoms have a definite higher limit to their valency. This will be true if an atom is a positively electrified body attracting to itself

^{*}Abegg, *Zeit. Anorg. Chem.*, xxxix, 330, 1904.

negatively charged electrons whether its positive charge is some approximate multiple of the elementary charge or not. In any case after taking in a sufficient number of electrons the system will become negatively charged and will then reject negative and attract positive charges.

The valence of an element in a compound depends upon the nature of the other component. It is difficult to see how this can be true unless the other components have different electrical charges. If they have equal charges the same number of their atoms should be held by the charge of the atom under consideration. Where more than one component may exist between atoms of only two kinds as in the oxygen and nitrogen series, it would seem that the opposite charges of the two constituents are neither equal nor is one an exact sub-multiple of the other.

All elements vary gradually from each other in their electric affinity. In this statement gradually apparently does not mean step by step, as they necessarily would vary if they all carried unit elementary charges or multiples of these charges.

In cases where the same element comes out of a compound in several electrovalence steps, the affinities of the higher valencies are generally weaker than the lower. This is shown, according to Abegg, in the fact that the heat of chemical reaction per equivalent is always greater for the lower steps than for the higher. Thus FeCl_2 and FeCl_3 , PbCl_2 and PbCl_4 , etc. The preparation of practically pure compounds of a determined valence step, as for example of FeCl_2 without the accompaniment of FeCl_3 , shows how enormously different the affinity of the two valence steps must be.

The formation of the higher combination steps, that is to say, the taking up of new valence charges is the more difficult the more charges have already been taken up.

The above propositions from Abegg's paper express exactly the conditions which would prevail from the assumption of the attraction for detachable electrons being the cause of valency. Thus if an electrically charged body have several bodies with electrical charges opposite to its own and equal to each other brought successively into its electrical field, each successive charge will be attracted by a weaker force than its predecessor; while in removing them each successive one will be held by a greater force than the one which preceded it.

The same element may have either a positive or a negative valency. This phenomenon is so well known that no examples need be given. Abegg refers especially to the compound ICl . Here is a compound made up of two atoms both of which may have negative valencies when combined with a metal, yet this compound dissociates in water and the prod-

ucts of its hydrolysis are HCl and IOH . Here the chlorine has taken the negative valence and combines with a positive hydrogen sub-atom, while the iodine replaces a positive sub-atom in the water molecule. Evidently if the chlorine had not had a stronger attraction for the detachable electron than had the iodine it would not have retained it.

Abegg gives hydrogen, boron, silicon, phosphorus, arsenic, antimony, sulphur and iodine as elements which may certainly take either positive or negative valencies according to the element with which they are combined.

The greater the atomic weight of an element in a group the stronger is its positive valence. This is equally true if stated, the greater the atomic weight of an element in a group the more electropositive it is in the voltaic series, and it has already been shown in this paper how the relative charges of the elements in a group may be calculated. Abegg gives many examples of this law. Thus, in the case of nitrogen and phosphorus, nitrogen, the lighter element, can hold only three atoms of chlorine with their attached electrons while phosphorus can hold, though in an unstable condition, five. Oxygen may have in unstable compounds a positive valence of four and sulphur of six. Oxygen is itself negative to sulphur in di-oxide and tri-oxide compounds. Iodine as a positive ion forms with the elements of its own group the compounds IF_3 , ICl_3 , IBr . Bromine, being less positive, can form the compounds BrF_3 , BrCl . Another fact referred to by Abegg which shows the difference in the tenacity with which the elements of this group hold to their valence electrons is shown in the weakening of the affinity of their gas molecules at high temperatures. Thus at high temperatures the iodine molecule dissociates completely, bromine partly, chlorine appreciably and fluorine scarcely at all. This seems to indicate that the charge of the connecting electron or electrons is approximately equivalent to the charges of both fluorine atoms, while in the other elements of the group the positive charge of a single atom becomes more and more nearly equivalent to the negative electronic charge as the atomic weight increases; accordingly the residual charge which constitutes cohesion is greatest for iodine and least for fluorine. Hence iodine is a solid at ordinary temperatures, bromine a liquid, chlorine an easily liquifiable gas and fluorine a relatively permanent gas.

ELECTROMAGNETIC PHENOMENA

The Electromagnetic Field

The magnetic effects of an electric current have long been known and the quantitative relations between a current and a magnetic field are well understood, but at the present time no physical theory which will account for these relations has ever been advanced. The fundamental phenomenon seems to be the attraction between two parallel currents in the same direction, and no explanation of this phenomenon seems to be forthcoming. In this respect the present paper does not differ materially from its predecessors. The theory of electric action which has been here outlined does, however, offer certain suggestions which may be worth considering.

A current in a metallic conductor seems to be entirely due to the passage of electrons along the conductor, while in an electrolytic solution it seems to be due to the drifting of both positive and negative ions, though, on the whole, to the positive ions: yet the magnetic effect of a given current seems to be the same in both cases.

That a magnetic field can be produced by the motion of electrical charges has been proved conclusively by Rowland and his students. Since the only phenomenon which we know accompanies an electric charge is an elastic strain in the ether, the magnetic field is apparently due to the motion of these fields of strain through the ether. The preceding discussion has seemed to show that both the electrons in a conductor and the ions in an electrolytic solution are passed along in a succession of periodic flights from one molecule to another. While the electron or ion is associated with an opposite charge in an atom or molecule it can have little, if any, external electric field. While it is moving from one atom to another it will have an external electric field, and since we know of nothing else to produce the magnetic field of a current, we must suppose it to be due to the motion of these short-lived electric fields.

Around a conductor carrying a current these electric fields will spread out with the velocity of light, and their centers of strain will advance with the velocity of an electron in its flight. What this velocity is we have no means of knowing, since we can on any assumption calculate only its average velocity, and we have no means of knowing what part of the time it is at rest. If all the electrons of a given cross section of the conductor advance together, as has been shown to be probable,

then these advancing electric fields form closed loops about the conductor and follow each other at regular intervals. It is easy to see from this view how two parallel currents in opposite directions must repel each other, since these waves going in opposite directions would have to pass through each other, and at such times the amplitude of the strain would be twice as great and the energy of the two sets of waves four times as great as of a single set. It is not so easy to see how two parallel currents in the same direction attract each other. If the waves of the two currents succeed each other at intervals of a half wave length they will, however, attract each other, since there would then be less potential energy of displacement in the ether between the currents than in the ether outside of them, and the reaction to this strain would force the currents toward each other.

Magnetism in Iron.

The question as to how the ether waves considered above would affect a magnet depends upon our theory of magnetism. Here there is substantial agreement upon a few points. The molecular theory of magnetism seems to be unquestioned. Ewing has satisfactorily accounted for the magnetic properties of iron on the assumption that these molecules are persistent and are oriented by their magnetic attractions and repulsions for each other; accordingly that a bar of iron is made an electromagnet by simply having its molecules rotated into a definite orientation.

The only magnetic molecule we know how to construct is one on the pattern of Rowland's rotating disc. Thus a molecule consisting of a number of electrons moving in a more or less circular orbit in a common plane about a positive atom would be such a disc magnet. The Zeeman phenomenon indicates that in some molecules the electrons are moving in broadly elliptical or circular orbits. The spectra of the elements indicate that some molecules have a very large number of electrons capable of vibrating or rotating under the influence of a central force. These spectra also show that iron has the greatest number of these oscillating electrons, nickel next and cobalt next to nickel.

Such a system of rotating electrons would set up a series of rotating strains in the ether following each other around the atom at definite intervals. This condition is strictly analogous to the assumed condition along a wire carrying a current. The waves produced by these rotating electrons travel in opposite directions on opposite sides of the molecule. In a magnet, when these molecular systems are all faced in the same direction and the planes of rotation of their elec-

trons are perpendicular to the magnetic axis, the surface currents produced by their electronic systems are all flowing in the same direction around the magnet. Over the surface of the magnet there is accordingly a series of successive, temporary electric fields moving around the magnet, which are strictly analogous to the temporary electric fields moving along a wire which is carrying a current. Accordingly, if lines of magnetic force are assumed lengthwise along a magnet there must be similar lines of magnetic force encircling a current.

The condition inside a solenoid would then be similar to the condition inside a magnet, except that it would be much less intense. Both regions would be filled with rotating electric fields. The proof of a similar rotation in the two cases is shown in the rotation of the plane of polarization of light. These rotating strains forming a series of vortex waves around the magnetic axis would extend out from both ends of the magnet and solenoid, and would spread through the ether with the velocity of light. When they met and formed closed loops these loops would contract, because the shorter they became the less the potential energy of strain in the ether. These vortex lines from opposite poles of a magnet would accordingly attract each other, while from like poles they would repel each other, like parallel currents in opposite directions.

The position of normal equilibrium of the magnetic molecules in iron would apparently be such that electrons between them would move in the same direction and follow each other, while the condition of magnetic saturation would be unstable, since the electronic fields would move in opposite directions between the molecules and thus increase the strain in the intervening ether.

For the same reason, a magnet in the vicinity of a current would set itself so that the electrons on the side toward the current would be moving in the same direction as those of the current.

The above short discussion of magnetism can be regarded as little more than a suggestion. It is offered in the hope that it may aid in clearing up some of the fundamental difficulties.

APPENDIX.

Note On the Electrical Theory of Benjamin Franklin.

There seems to be a general misunderstanding regarding Franklin's theory of electricity. Smyth, in his *Life and Writings of Benjamin Franklin*, Vol. 1, p. 96, quotes with apparent approval Garnett's *Heroes of Science* as saying of Franklin's views, "They are perfectly consistent with the views held by Cavendish and Clerk Maxwell, and though the phraseology is not that of modern text books, the statements themselves can hardly be improved upon today." Maxwell, in his *Electricity and Magnetism*, Vol. 1, p. 41, describes the one fluid theory of Electricity as follows: "In the theory of One Fluid everything is the same as in the theory of Two Fluids except that, instead of supposing the two substances equal and opposite in all respects, one of them, generally the negative one, has been endowed with the properties and name of Ordinary Matter, while the other retains the name of the Electric Fluid. The particles of the fluid are supposed to repel one another according to the law of the inverse square of the distance, and to attract those of matter according to the same law. Those of matter are supposed to repel each other and attract those of electricity."

Sir Oliver Lodge says on page 202 of his book, entitled *Electrons*: "The positive electron has not, so far as I know, been as yet observed free. Some think it cannot exist in a free state, that it is in fact the rest of the atom of matter from which a negative unit charge has been removed; or, to put it crudely—that 'electricity' repels 'electricity' and 'matter' repels 'matter,' but that Electricity and Matter in combination forms a neutral substance which is the atom of matter as we know it. Such a statement is an extraordinary and striking return to the views expressed by that great genius, Benjamin Franklin."

It is only fair to Sir Oliver Lodge to assume that he has not read Franklin's papers on Electricity, as otherwise he could not have made such a misleading statement in regard to his theory. The other writers who have been quoted as referring to Franklin's electrical theory may not have appreciated the fundamental difference between it and the one fluid theory described by Maxwell, but the author of *Modern Views of Electricity* could scarcely have failed to be impressed with this difference in even a perfunctory reading.

In a paper entitled *Opinions and Conjectures. Concerning the Properties and Effects of the Electrical Matter, etc.* sent by Franklin to Peter Collinson under date of July 29, 1750, he discusses the nature of the electrical matter which he had previously spoken of as the electrical fire. As this was written at the close of his electrical experiments, three years after he had first proposed the theory of a single electricity, it evidently states his mature views. The first five paragraphs of his discussion are as follows:

"1. The electrical matter consists of particles extremely subtle, since it can permeate common matter, even the densest metals, with such ease and freedom as not to receive any perceptible resistance.

"2. If any one should doubt whether the electrical matter passes through the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him.

"3. Electrical matter differs from common matter in this, that *the parts of the latter mutually attract* (the italics are mine), those of the former mutually repel each other. Hence the appearing divergency in a stream of electrified effluvia.

"4. But though the particles of electrical matter do repel each other, they are strongly attracted by all other matter.

"5. From these three things, the extreme subtilty of the electrical matter, the mutual repulsion of its parts, and the strong attraction between them and other matter, arise this effect, that, when a quantity of electrical matter is applied to a mass of common matter, of any bigness or length, within our observation (which hath not already got its quantity) it is immediately and equally diffused through the whole."

Neither in these paragraphs nor in any other of Franklin's electrical papers have I been able to find any suggestion of the notion that electrical matter and common matter "are equal and opposite in all respects" or that there is such a phenomenon as the "neutralization" of electrical charges, or of electrical matter and common matter. Franklin everywhere speaks of the earth and bodies upon its surface as having a common stock of the electrical fire or electrical matter. In his view, an unelectrified body is one in which the electrical fluid is in equilibrium with that in the earth. A positively electrified body is one in which this fluid has been compressed, and a negatively electrified body is one in which it has been rarefied. This is well shown in a letter to Peter Collinson, dated July 11, 1747. After speaking of two men standing on wax and electrifying themselves, one from a glass tube and the other from the rubber, while a third man stands on the floor near them, he

says, "These appearances we attempt to account for thus: we suppose, as aforesaid, that electrical fire is a common element, of which every one of the three persons above mentioned has his equal share, before any operation is begun with the tube. A, who stands on wax and rubs the tube, collects the electrical fire from himself into the glass; and his communication with the common stock being cut off by the wax, his body is not again immediately supplied. B (who stands on wax likewise), passing his knuckle along near the tube, receives the fire which was collected by the glass from A; and his communication with the common stock being likewise cut off, he retains the additional quantity received. To C, standing on the floor, both appear to be electrified: for he having only the middle quantity of electrical fire, receives a spark upon approaching B, who has an over quantity; but gives one to A, who has an under quantity. If A and B approach to touch each other, the spark is stronger, because the difference between them is greater; after such touch there is no spark between either of them and C, because the electrical fire in all is reduced to the original equality."

These quotations seem to make it certain that Franklin regarded the earth and all bodies on its surface as being at all times charged with electricity, and that an insulated body was regarded as electrified only when its electrical charge was not in equilibrium with the electrical charge of the earth. In this respect his one fluid theory is fundamentally different from the one fluid theory as defined by Maxwell.

PLATE I.

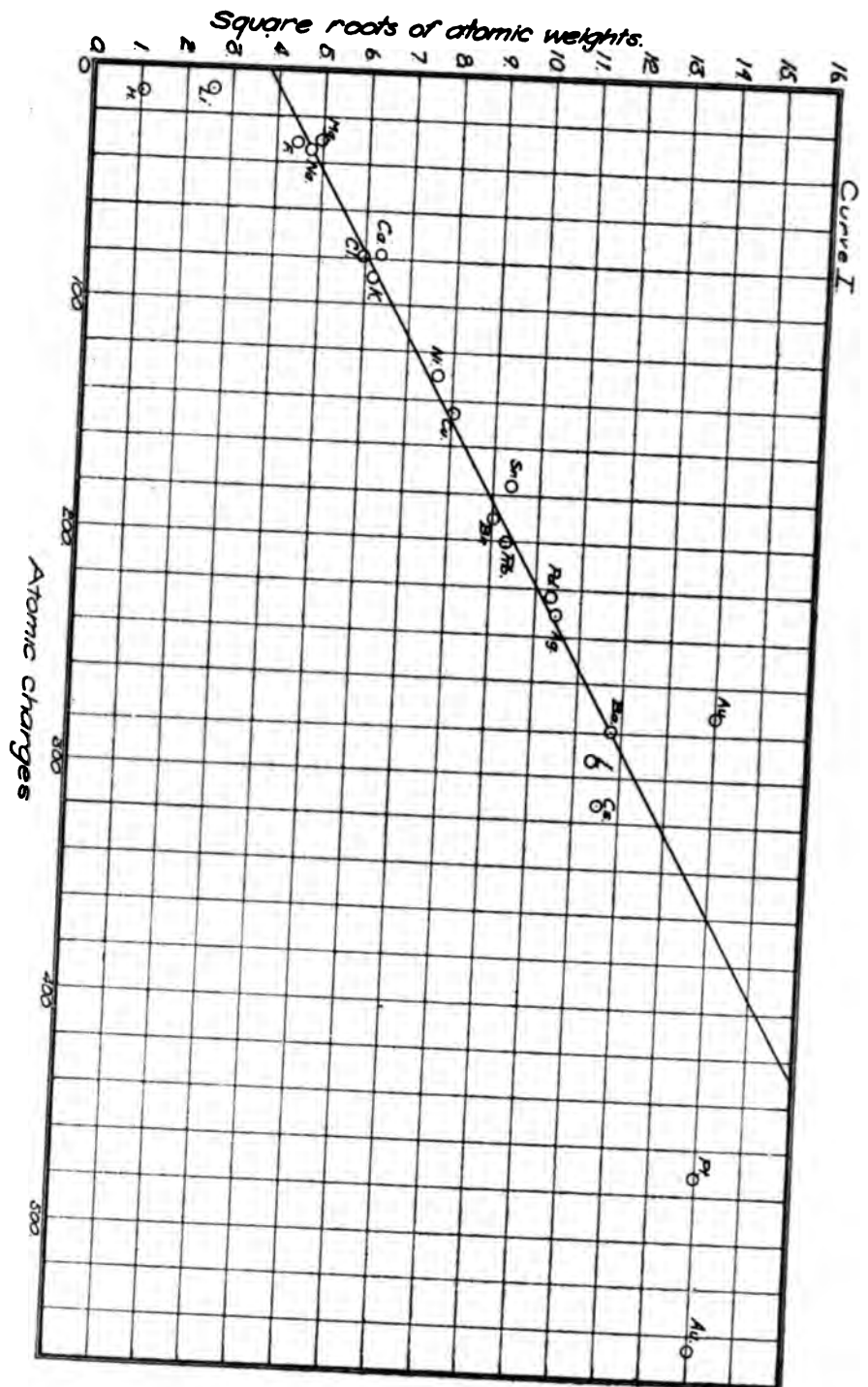
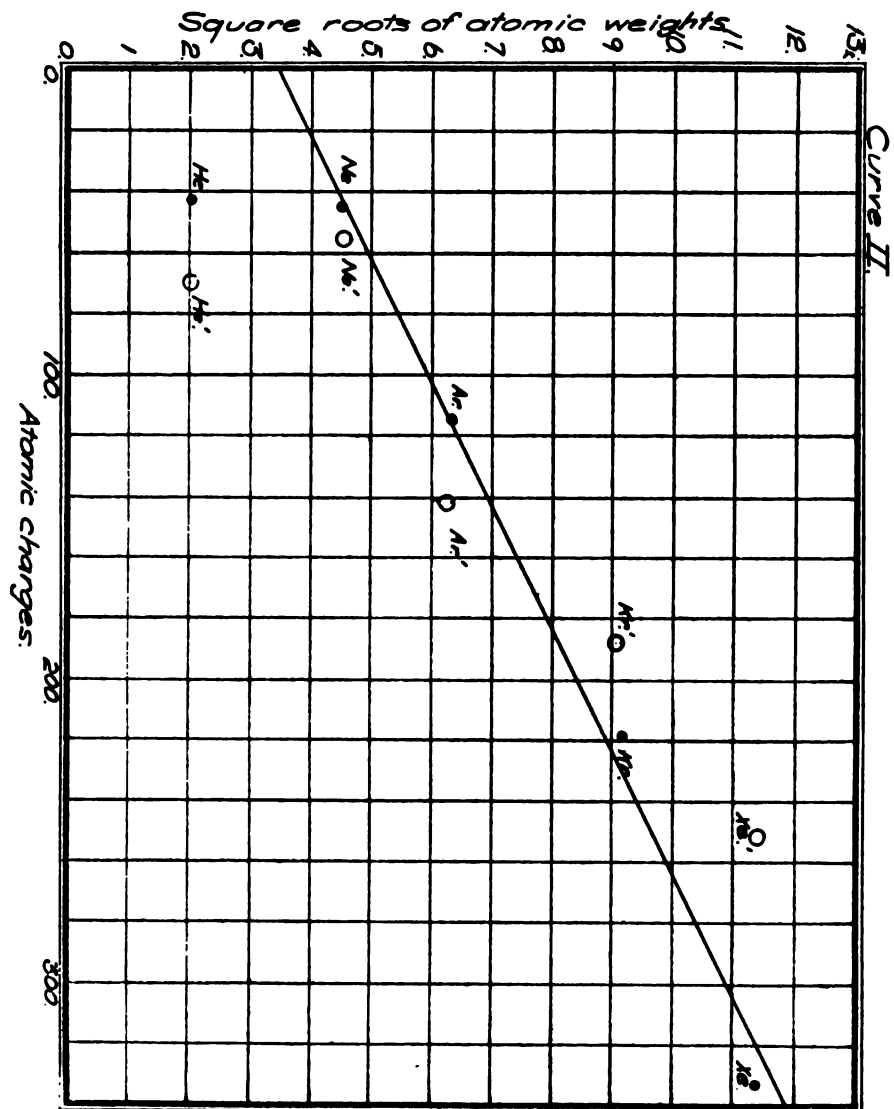
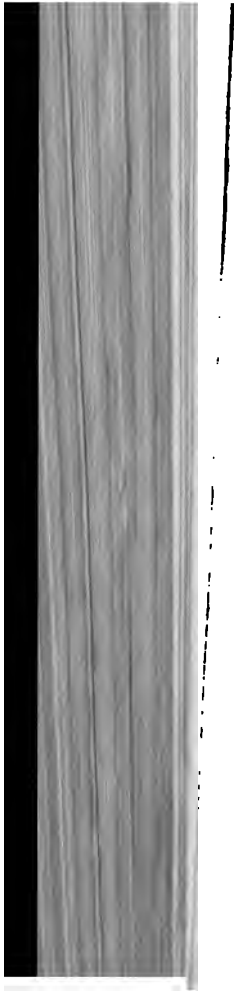


PLATE II.



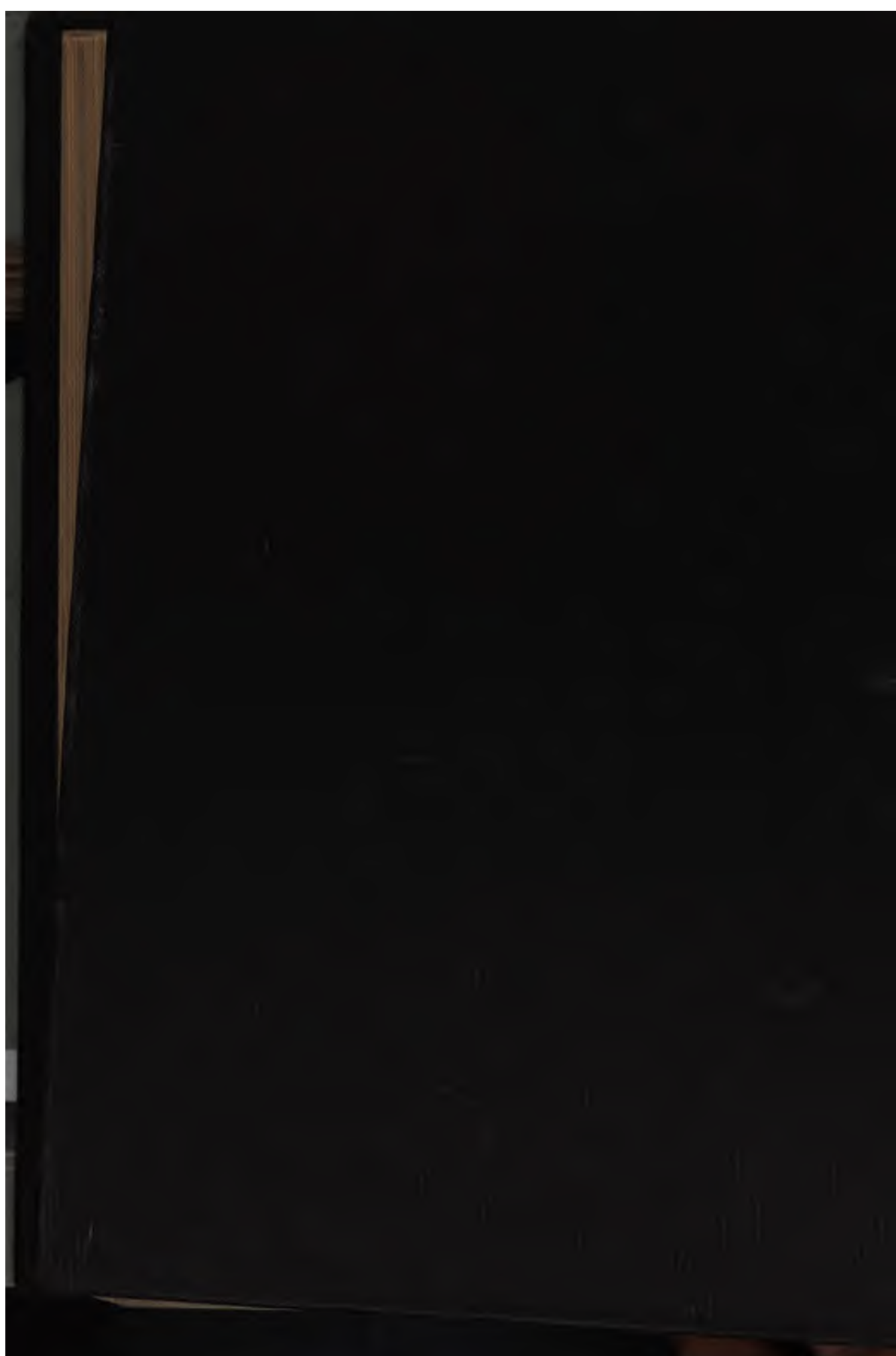


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A Physical Theory of Electrification

BY

FERNANDO SANFORD

Professor of Physics

WITH TWO PLATES AND ELEVEN TEXT FIGURES

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TABLE OF CONTENTS.

	PAGE
INTRODUCTION	5
Elements of the Theory.	
ELECTROSTATIC PHENOMENA.....	11
Electric Repulsion and Attraction.	
Electrical Induction.	
The Electrical Condenser.	
The Hollow Conductor.	
Electric Density and Surface Curvature.	
Surface Curvature and Induction.	
Metallic Conductivity.	
Contact Electromotive Force.	
Cohesion.	
ELECTRIC CURRENTS	47
Electrolysis.	
The Voltaic Cell.	
Charges of Electrolytic Ions.	
ATOMIC CHARGES	55
Positive Charges of Ions from Hot Metals.	
Charges of Monatomic Gas Molecules.	
Atomic Charges and Solubility.	
Charges of Atomic Ions in Flames.	
Atomic Charges and Chemical Valence.	
ELECTROMAGNETIC PHENOMENA	64
The Electromagnetic Field.	
Magnetism in Iron.	
APPENDIX	67
Note on the Electrical Theory of Benjamin Franklin.	
PLATE I.	
Atomic Charges and Square Roots of Atomic Weights.	
PLATE II.	
Solubilities and Square Roots of Atomic Weights.	



INTRODUCTION.

The following attempt at a mechanical explanation of some of the simpler phenomena of electrification is due to the opinion that the Faraday-Maxwell theory, based, as it is, upon the assumption of two electricities capable of neutralizing each other's properties, and of attraction as the fundamental phenomenon—making repulsion a special case of attraction—has proved inadequate to explain many of the well known phenomena of static electricity, and has broken down completely in attempting to explain current electricity.

I have tried elsewhere* to show that the physical lines or tubes of force which are an essential part of this theory are incompetent to explain the phenomena for which they were invented, and are inconsistent with our experimental knowledge of facts. It is the purpose of this paper to attempt to show that the mechanical theory of electrification may be greatly simplified by starting with Franklin's theory of a single electricity** and by regarding repulsion, rather than attraction, as the fundamental phenomenon.

Since it is the purpose of this paper to present a physical, rather than a mathematical, theory of electricity, no attempt has been made to state the subject in a mathematical form. The quantitative relations of the electric field have been very satisfactorily expressed both in terms of action at a distance and in terms of lines or tubes of force. It is believed that the equations based upon the notion of lines of force will apply equally well to this presentation of the subject by merely changing the necessary plus and minus signs.

The Electrical Substance.

We have at the present time very definite experimental knowledge of a single electrical substance, divisible into very small particles which are usually associated with other small material particles to make up the ordinary chemical atoms and molecules, but which may exist in bodies in excess of the number actually combined with material particles. I

*Sanford, Phys. Rev. xxvi, 306, Apr. 1908.

**See note on The Electrical Theory of Benjamin Franklin at the end of this paper.

have ventured to call the sub-atoms with which electrons are combined the material part of the atom, as distinguished from the electrical part, because the atomic mass seems to be chiefly associated with this part, and mass is regarded as the material constant of nature.

Electrification.

Electrification was assumed by Franklin to consist of an excess or a deficiency of the electrical fluid (which he sometimes called the "electrical fire") which was assumed to exist as a common stock in the earth and all bodies connected with it. A body was positively electrified when it contained an excess, and a body was negatively electrified when it contained a deficiency of this electrical fire. Applying this definition to our present state of knowledge, we may say that a body is resinously or negatively electrified (using negatively as meaning resinously, and not as indicating a deficiency of the electrical fluid) when if put in electrical contact with the earth or with the inside of a hollow conductor on the earth it will lose electrons, and it is vitreously electrified when if placed under similar conditions it will gain electrons.

In this sense, non-electrification is a relative condition. A body may be non-electrified on the earth, when if moved to another planet it might be electrified.

Since this definition is, in a way, a departure from general usage, it may be well to give it further consideration. On the assumption of two electrical fluids it was supposed that these fluids existed in exactly equal quantities in the earth and in bodies on its surface, and that they were capable when combined of so neutralizing all each other's properties that the existence of either or both could not be detected by any known means. This notion of neutralization has been carried over into the single fluid theory, only here the atoms are regarded as essentially electropositive, just as electrons are essentially electronegative, and it has been assumed that there is just a sufficient number of electrons in the world to neutralize, that is, to render non-attractive and non-repulsive, the atoms of bodies.

This assumption seems to be based wholly on the supposed electrical neutrality of the earth as a whole. If it be possible to show that there is no necessity in electrical theory for such a neutral condition, the argument for equivalent numbers of electrons and atoms falls.

Electrification of the Earth.

If we consider the experimental arguments for or against the equivalent number of electrons and positive atoms, they seem to be universally against such assumption. Even if there were equivalent numbers of the two kinds of charged particles to begin with, there seem to be many reasons why this equivalence could not be maintained.

For example, radioactive changes are taking place on the earth, and apparently in the atmosphere. There are indications that these changes have been more important in the past than they are at the present time. In some of these changes the negative electrons are sent off at very high speeds, and it seems probable that some of them have escaped from the earth.

On the other hand, it seems probable that the earth is receiving electrons from the sun. There are evidences of extensive radioactivity, or at least of extensive disassociation of atoms, on the sun, and there are reasons for thinking that streams of electrons are being discharged from the sun to the earth. The Aurora is generally attributed to a discharge of electrons taking place toward the earth through the very highly rarefied upper atmosphere. No corresponding discharge in the opposite direction is known.

In this connection Sir Oliver Lodge* says: "The earth is in fact a target exposed to cathode rays, or rather to electrons emitted by a hot body, viz., the sun." Again: "The gradual accumulation of negative electricity by the earth is a natural consequence of this electric bombardment extending to greater distances across space, where no residual matter exists; and the fact that the torrent of particles constitutes an electric current of fair strength, gives an easy explanation of one class of magnetic storms; these storms having long been known, by the method of concomitant variations, to be connected with sun spots and aurorae."

The phenomenon of radioactivity, itself, seems to indicate that the electrical conditions on the earth have changed since the present unstable atoms were originally formed. If the atoms consist of electropositive parts combined with electrons, the characters of the groups which constitute the atoms were determined in the beginning by the relative numbers of electrons and positive sub-atoms. If this relation should change with time, certain of the original combinations would become unstable. In fact, the changes which are supposed to occur in the successive disin-

*Lodge, *Electrons*, p. 168.

tegration of radium, indicate that there are more alpha particles than electrons set free, even though two electrons are required to neutralize the charge of one alpha particle. Thus, in the complete disintegration series of uranium as given by Soddy,* there are seven alpha particles to four electrons set free. In several changes, only alpha particles are given off. If the atom was neutral before the alpha particle escaped it must have been negatively charged afterward, yet no less than four successive changes of this kind are shown, beginning with the parent of radium and ending with Ra-A.

Aside from the above argument, we have strong experimental proof that the earth is an electrically charged planet. It is well known that the electrical potential rises rapidly with distance above the earth. Within the range of most observations this change is very irregular, though usually in the same direction. This irregularity has been attributed to the irregular distribution of charges on clouds in the earth's atmosphere, which, in order to account for the observed rise of potential must usually be positively electrified. Observations made in the highest balloon ascensions, which are certainly above most of the positively charged clouds, still show a rise of potential which seems to tend toward a constant value. From the sixteen recorded observations on the rise of potential at heights between two and three miles which I have been able to find, the average rise is 10.7 volts per meter. The nine recorded observations above three miles give an average rise of 7.1 volts per meter. Two of these were at heights of approximately four miles, and were respectively 8.4 and 7.9 volts per meter.

These numbers are undoubtedly too small, since in none of the recorded ascensions has there been suitable provision for discharging the balloon. In ascensions to heights of four miles the total rise of potential has been approximately 200,000 volts. If the balloons have retained the electrical charge which they had on leaving the earth, they were about 200,000 volts electronegative to the surrounding air when these highest measurements were made. Since the measurements have regularly been made at a distance of only a few meters below the balloon, the error due to the charge of the balloon has evidently been considerable.

The total change of potential for a height of one mile near the surface, assuming the earth to be an electrified sphere, should be about $1/2000$ of the potential of the earth. Assuming the change to be at the rate which has been observed at a height of four miles, the negative potential of the earth would be about 25,600,000 volts. This estimate

*Soddy, *The Interpretation of Radium*, p. 205.

is undoubtedly of very little value, but it at least indicates that the earth has a negative charge.

If it be assumed that the number of positive sub-atoms in the earth is just sufficient to neutralize the charges of the electrons, then there must be a great excess of positive sub-atoms in the upper regions of the atmosphere to account for the observed rise of potential. The reverse of this seems to be the case, as shown by the great height at which the auroral light has been observed. Hann* gives a number of averages of the height of the auroral light as estimated from a large number of observations by different observers. These averages vary from 35 miles to 140 miles, and Hann regards it as definitely established that auroras may be as much as 125 miles high. Arrhenius† quotes as among the best measurements those of Paulsen, in Iceland, which were made by the use of theodolites at two stations connected by telephone, and which gave the maximum height of the polar light as about 250 miles. The only reasonable explanation yet proposed for the aurora is that it is due to the discharge of negative electrons through the rarefied upper air. This would indicate that the upper limits of our atmosphere are not positively electrified.

Our experimental data accordingly seem to indicate that the earth is not electrically neutral, but that it has a high negative charge which extends at least to the upper limits of its atmosphere.

Nature of the Earth's Electrical Field.

Any hypothesis as to the nature of an electrical field must ultimately resolve itself into one of two possible fundamental assumptions. An electric attraction or repulsion must be either a true action at a distance, or it must be conveyed by an intervening medium. Since the discoveries of Faraday, the second assumption has seemed the only tenable one. Hence all modern electrical theories have been ether theories, and all explanations of static electrical attraction and repulsion have been based upon the assumption of some kind of an elastic stress in the luminiferous ether. This being the case, an electric field is the region throughout which this ether stress may be detected.

It is known from experiment that the electric field about a spherical, charged conductor falls off according to the inverse square law.

*Hann, *Lehrbuch der Meteorologie*, S. 4.

†Arrhenius, *Lehrbuch der kosmischen Physik*, S. 912. See also, *Das Werden der Welten*, chapter v.

This being true, the ether stress about a sphere as large as the earth would be of nearly the same magnitude on all sides of a small body. That is, if we think of this stress as a pressure exerted by the electrons in the earth upon the surrounding ether, this pressure at a point within the ether would be nearly of the nature of a hydrostatic pressure, so that a small body charged to the same potential as the earth would be under virtually the same pressure in all directions anywhere upon the earth's surface or near the earth.

Elements of Our Theory.

The fundamental assumptions of our electrical theory are, accordingly, as follows:

1. An all pervading ether permeating all known bodies, passing between or through the atoms of bodies.
2. An electric substance consisting of very small particles—electrons or corpuscles—which upon any ether theory must be looked upon as centers of strain in the ether. It is unnecessary to make any assumption as to whether the electron is *only* a center of strain in the ether, but it seems necessary to assume, as has always been done, that the ether in the immediate vicinity of an electron is in a state of strain analogous to an elastic strain in material bodies.

It is immaterial for the purpose of the following discussion what the particular nature of this strain may be if it be allowed merely that it is a strain against which there is an elastic reaction.

3. The material, or, so-called, electropositive constituents of the atoms. These are themselves apparently composed in part of electrons, but whether they consist entirely of electrons or not is a question which is not involved in the present discussion.

4. The earth as a great reservoir of electrons from which all bodies on the earth may draw an unlimited supply, or to which all bodies may give off electrons.

ELECTROSTATIC PHENOMENA.

Electric Repulsion.

If it be assumed that the ether about an electron is in a condition of elastic strain, it necessarily follows that there will be a force of repulsion between electrons. For if a given volume of the ether contain a certain number of electrons, any potential energy which may exist on account of their elastic strain will be a minimum when this strain is uniformly distributed throughout the system, hence the condition of most stable equilibrium will be that in which the electrons are uniformly distributed throughout the ether. This consideration renders unnecessary any further explanation of repulsion, and it makes such explanation impossible without a further description of the character of the ether strain.

But while repulsion alone will tell us nothing further of the character of the electric strain in the ether, the phenomena of radiation enable us to further describe this strain as one analogous to a distortional, rather than a compressional, strain in a material body.

Properties of the Ether.

Since the ether seems to possess properties analogous to an elastic solid, we may conveniently think of it as being stretched about an electron or a group of electrons just as a rubber balloon or a cavity in an elastic solid may be stretched by forcing into it a fluid under heavy pressure. In an elastic solid, the walls of such a cavity may be both stretched and compressed at right angles to the stretch.

It is not contended that this is the only kind of a strain which will account for the repulsion between electrons, but only that it is one kind which will do so.

Maxwell gave the name Electrical Elasticity to the resistance which the ether offers to an electric strain. This resistance is taken as proportional to the repulsion or attraction between two given electrical charges, and has been shown to be less in all material bodies than in a vacuum, and to be least in metallic conductors. Defined in this way, the electrical elasticity is the reciprocal of the specific inductive capacity.

The ether offers no known resistance to moving electrons or moving charges until their velocity approaches the velocity at which a strain is naturally propagated through the ether.

The ether is the best known insulator of electric charges. That is, electric charges are held to bodies with stronger forces in a vacuum than in any known insulating body.

(In this connection a question suggests itself which seems to be ignored in all attraction theories of electricity. According to the ordinary attraction theory the electrons are drawn to the surface of a negatively charged body by their physical tubes of force running to opposite charges on some other conductor. The pull of these tubes is greater through a vacuum than through any known material dielectric. Electric charges once set in motion in a vacuum move with no appreciable resistance until their velocity is very great. It is generally assumed that there is but one tube of force to an electron, and this is pulling it away from its conductor, but supposing another tube of force, or many tubes of force, to be connected with positive charges within the conductor, still the specific inductive capacity of a metallic conductor is so great that the single tube of force through the vacuum would be more than equivalent to all of them. Why, then, is a vacuum an insulator?)

Electrical Pressure Over the Surface of a Conductor.

Since the ether within a conductor still possesses some electrical elasticity, the electrons within the conductor are still centers of ether strain and accordingly repel each other. At the surface of the conductor this repulsion must be balanced by the stress in the ether outside the conductor. There must accordingly be an electrical pressure exerted upon the surrounding ether by the charge within a conductor. Since electrical charges are free to move about within or over a conductor, the electrical pressure of the ether must be the same over the whole surface of a charged conductor or system of connected conductors when their charges are in equilibrium.

Since the electrical pressure is proportional to the electrical elasticity of the surrounding ether, it must be greater in a vacuum than in any material dielectric. Accordingly, when a charged body is surrounded by a dielectric of high specific inductive capacity, the electrical pressure over its surface is diminished. If it is desired to make the electrical pressure over its surface as great as it was in a vacuum, its charge must be increased. Hence its electrical capacity is said to be increased in a medium of high specific inductive capacity.

Thus, if two equal spheres be connected and charged negatively in air, and then one of them be immersed in paraffin, electrons will flow

from the sphere which is in air to the one which is in paraffin, until the electrical pressure becomes equal over the surface of both.

Recapitulation of Fundamental Assumptions.

To recapitulate, we have the following fundamental postulates by which to explain electrical phenomena:

1. An elastic ether, pervading all known space, passing between and perhaps through the atoms and molecules of all bodies; its electrical elasticity being less between the atoms and molecules of bodies than in free space, and relatively much less in conductors than in non-conductors. From the transverse character of light waves and electric waves in the ether, we regard its electrical elasticity as analogous to rigidity in material bodies. We have no data upon its compressional elasticity, but we have reasons for regarding it as very great.

2. We have electrons which, whatever their nature, act as centers of strain in this medium, and on this account, and by virtue of the elastic reaction of the ether to this strain, repel each other. When in free ether and at a distance from material bodies they appear to have perfect freedom of movement.

3. We have the atoms of material bodies which are in part made up of electrons, but of whose structure we know very little.

4. We have the earth containing a sufficient number of electrons, both combined and free, to produce a field of great ether strain around it.

5. On account of the great size of the earth, the electrical pressure in its field becomes nearly a hydrostatic pressure at the surface of the earth, and in closed hollow conductors connected with the earth it becomes a true hydrostatic pressure.

A Conductor Analogous to a Porous Cavity in the Ether.

The conditions of the ether with reference to elastic pressure in the earth's field, and more especially in a hollow conductor connected to earth, are analogous to those of an elastic, nearly incompressible solid, as a jelly or a mass of India rubber, surrounded by a fluid under heavy pressure. A metal sphere or other conductor insulated from other bodies is analogous to a porous cavity in the solid which is under pressure. This cavity may be filled with a fluid under the same pressure as the surrounding fluid, or it may be filled to a greater or a less pressure. These three conditions correspond to Franklin's ideas of an uncharged, a positively charged and a negatively charged conductor, respectively. In our present knowledge of the subject, the one filled to a greater pressure than the surrounding fluid corresponds to a resinously, instead of a vitreously, electrified conductor, as Franklin sup-

posed. The reason that Franklin regarded the vitreously electrified body as the one positively electrified apparently resulted from the accident that he used a glass tube instead of a stick of sealing wax as his source of electrification.

This analogy of a conductor to a porous cavity in the ether is not new. Franklin speaks of matter as "a kind of sponge to the electrical fluid." Sir J. J. Thomson* in discussing the two theories of metallic conductivity, says: "A piece of metal on the first of these theories contains a large number of free corpuscles disposed through its volume. These corpuscles can move freely between the atoms of the metal just as the molecules of air move freely about in the interstices of a porous body. The corpuscles come into collision with the atoms of the metal and with each other, and at these impacts suffer changes in velocity and momentum; in fact, these collisions play just the same part as the collisions between molecules do in the kinetic theory of gases."

If the corpuscles are prevented from escaping from the conductor by the surrounding ether, it follows from the above theory that they must exert a pressure upon this ether corresponding to the pressure exerted by the molecules of a gas upon the sides of the containing vessel. This pressure would vary with the number of corpuscles confined in the metal, and would be greater for a resinously electrified and less for a vitreously electrified than for the normal unelectrified body.

Further Analogy of Electrical Pressure to Fluid Pressure.

In following out the analogy of a conductor to a porous cavity in an elastic solid, let us suppose a block of India rubber to contain a porous, spherical cavity which is filled with a fluid, as a gas, under sufficient pressure to distend the cavity and stretch its walls. If the block be incompressible, its external volume will be increased as much as the volume of the cavity has been enlarged, but the stretching of the rubber around the cavity will cause a pressure perpendicular to the stretching force tending to compress the material about the cavity. If the block be compressible, the rubber will be actually compressed and the external increase in volume will not equal the increase in volume of the cavity. In either case there is a pressure exerted outward normal to the surface of the cavity.

In terms of our ether theory, this corresponds to a resinously charged conductor surrounded by a portion of the elastic ether, say the ether within a room. In order to bring the conditions into closer

*Thomson, The Corpuscular Theory of Matter, p. 51.

agreement with our assumptions regarding the ether, it will be necessary to assume that the rubber block is, itself, under external fluid pressure. Thus the ether within the conducting walls of a room is surrounded by the electric fluid within these walls, which is under the normal pressure of the electric fluid within the earth, and which in turn transmits this pressure to the ether which it surrounds.

It is plain that no matter how great this external hydrostatic pressure upon the block of rubber, and no matter how much the block were compressed thereby, it would have no tendency to drive the distended cavity in one direction more than in another, provided the material of the block were perfectly elastic.

Analogy to An Electrified Body in a Field of Non-Uniform Electrical Pressure.

If the block containing the distended fluid cavity were compressed at one end more than at the other, the external pressure upon the fluid contents of the cavity would be greater on one side than on the other, and the fluid would tend to move into the region of least external pressure.

Thus in Fig. 1, let A represent the distended cavity in the block B D, and place the wedge-shaped weight, C, upon the block. The block will then be compressed at the end, D, and the pressure upon the fluid in A will be greater upon the side toward D than upon the side to-

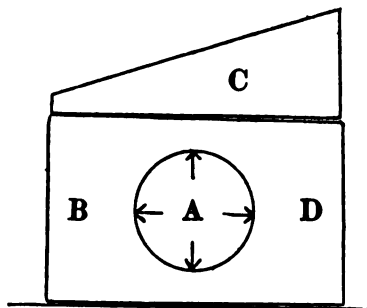


Fig. 1.

ward B. If free to move, the distended cavity will be driven toward the end B. In other words, the compressional strain in the block is greater around A and at D than it is at B. Since the condition of least potential energy, due to this strain, will be that in which the strain is as nearly as possible uniformly distributed through the block, there will be an elastic force tending to drive A into the region of least compressional strain, which is toward B.

The above condition is clearly analogous, on the assumptions of our theory, to a resinously electrified body in a region of unequal electrical pressure.

If we assume a porous cavity in an elastic block under hydrostatic pressure to contain a fluid whose pressure upon the surrounding material is less than the external hydrostatic pressure, the block will be compressed by the external pressure, but its substance will be compressed less than it would be if the fluid pressure within the cavity were equal to the external pressure. If, in addition to the external hydrostatic pressure, the block be more compressed at one end than at the other, as in Fig. 1, the cavity containing the fluid will, if free to move, move into that part of the block which will make the compressional strain most nearly uniform throughout. Since the compressional strain is greatest under the heavy end of the weight and least about the porous cavity A, there will be a force tending to drive A toward D. This is analogous to a vitreously charged conductor in a region of unequal electrical pressure. Accordingly, in a region where the electrical strain in the ether is falling off from a higher to a lower value, oppositely electrified bodies will be impelled in opposite directions by the elastic reaction to this strain. From this principle we may explain all cases of electric attraction and repulsion.

Repulsion of Two Similarly Electrified Bodies.

If the elastic block in our analogy be placed under a true hydrostatic pressure, as in a closed tank filled with fluid under an external pressure, and two spherical, porous cavities, as A and B in Fig. 2, be near together and be filled with fluid under a greater pressure than

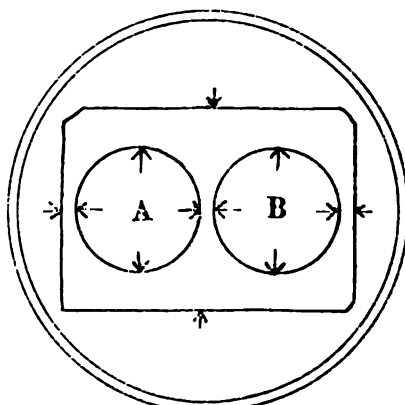


Fig. 2.

the external hydrostatic pressure upon the block, the region of greatest compression will be between the two cavities. Since the elastic reaction to this strain tends to drive each into a region of lower compressional strain, there will be a force tending to separate the two cavities. Thus two resinously electrified bodies in a field of hydrostatic electrical pressure repel each other.

If the two cavities be filled with fluid under a less pressure than the external hydrostatic pressure, as indicated in Fig. 3, each will tend

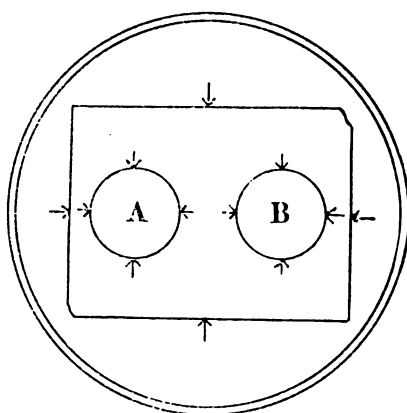


Fig. 3.

to move into a region of greater compressional strain, and they will tend to separate as before. Thus two vitreously electrified bodies repel each other.

Attraction Between Two Oppositely Electrified Bodies.

It follows from what has preceded that if we place within an elastic block under hydrostatic pressure two porous cavities filled with fluid, one to a greater and one to a less pressure than the external hydrostatic pressure, as indicated in Fig. 4, these cavities will, if free to move, approach each other. This corresponds to the attraction between two oppositely electrified bodies.

If the spheres in Fig. 4 are allowed to touch each other, the fluid, or the electricity, will flow from the one in which it is under the greater pressure into the one in which it is under the less pressure until the

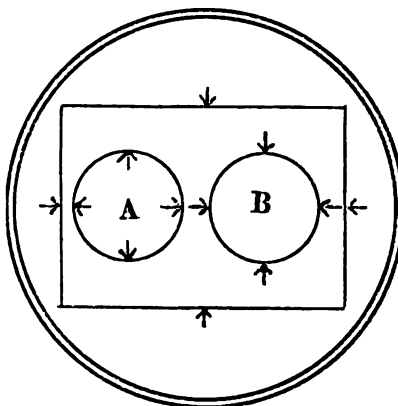


Fig. 4.

pressure is the same in both. If after this has occurred the pressure within both is either greater or less than the external hydrostatic pressure, they will again separate.

Electrical Induction.

If a resinously electrified conductor, as A in Fig. 5, be brought near an unelectrified, insulated conductor, as B, the distribution of the electrical fluid in B will be greatly modified. For example, if another small, insulated conductor, as C, be touched to B at the end a, it will lose electrons to B and become vitreously charged; if the same insulated conductor be touched to B at b, it will gain electrons and become resinously charged, while an intermediate region can be found on B from which C will take no charge of either kind.

If the small conductor be placed at a distance from both A and B and be connected to B by a wire, it will take the same resinous charge, no matter where the wire touches the surface of B. If it be placed near A and joined to B by a wire, it will take the same vitreous charge from any part of the surface of B. If it be placed in the intermediate region where it will take no charge from B by contact, it will take no charge when joined by a wire to any part of B. Accordingly, if the small conductor be joined by a wire to any point on B, it may take, according to its position, a vitreous charge, a resinous charge or no charge at all from B.

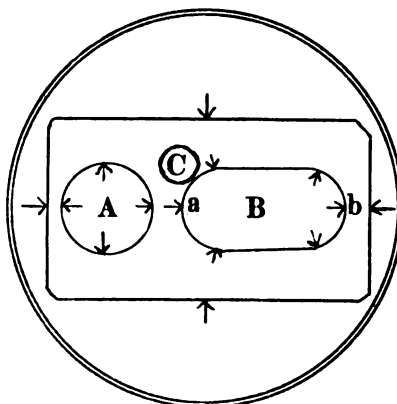


Fig. 5.

If B be connected to earth, the small conductor can no longer take a resinous charge from any part of its surface, but may still take a vitreous charge, which is greater the nearer to A it is when touched to B.

To explain these phenomena in terms of fluid pressure, let A and B, in Fig. 5, be porous cavities in an elastic block under external hydrostatic pressure, and let A be filled with a fluid to a pressure greater than the external hydrostatic pressure, while B was filled with a fluid to exactly the external hydrostatic pressure before it was brought near A. It is easy to see that as B is brought near A the external pressure upon its fluid becomes everywhere greater than the normal hydrostatic pressure, and that this pressure is greatest on the end near A and least on the end farthest from A. Since the fluid in B cannot sustain a different pressure on different parts of its surface, it is driven toward the end farthest from A, while the elastic substance around the end nearest A is stretched inward and made to support a part of the external pressure, as in a cavity which has been filled to less than the external pressure. When equilibrium is established, the fluid pressure in B will be everywhere the same. It will be less than in the elastic block near A, and it will be greater than in the elastic block at a distance from A. There will accordingly be some distance from A at which the pressure in the elastic block will just equal the pressure of the fluid in B.

Suppose another small porous cavity, as C, to be filled with fluid to just the external hydrostatic pressure and to be brought near B. If brought near the end a, its fluid will be under a greater pressure than the fluid in B, and if put in communication with B some of its fluid

will flow into B until the pressure becomes the same in both. If touched to B at the end b, it will be in a region of less external pressure than the pressure upon the fluid in B and it will accordingly gain fluid from B. Some intermediate region can be found where the external pressure upon its fluid will exactly equal the pressure upon the fluid in B, and if touched to B while in this position it will neither gain nor lose fluid by the contact.

If placed at a distance from A and joined to B by a tube, it will take the same amount of fluid from B, no matter where the tube joins B. If placed near A and joined to B by a tube, it will lose the same amount of fluid to B, no matter where the tube joins B. If joined to any point on B by a tube and moved about, it will gain or lose fluid according as it is in a region where the external pressure upon its fluid is less or greater than the pressure on the fluid in B.

Charging By Induction.

If an opening be made through the block from B to the outside fluid, some of the fluid will be forced out of B and the fluid pressure in B will become the same as the external fluid pressure upon the block. Under these circumstances, the small cavity, C, would lose some of its fluid if touched to any point on the surface of B, since the pressure within the block due to the increased fluid pressure in A would be greater than the outside fluid pressure for a distance about A greater than the distance to any point of B. There would be no place in the block where the pressure upon the fluid in C would be less than the external fluid pressure, hence there would be no place where fluid would be forced into C from B.

If B, after being put into communication with the external fluid, be again insulated and A be removed, B will be left with less than its normal charge of fluid. This corresponds to the vitreous electrification of a body by induction.

It will be readily seen that if A had been charged with less than the normal quantity of the fluid in the beginning, the pressure in the material medium about it would have been less than the external hydrostatic pressure, and if the above experiments had been repeated the flow of the fluid would have been in the opposite direction each time. Under these conditions, if B had been connected to the outside fluid, some fluid would have entered it, and if it had then been insulated and A had been removed, B would have been resinously charged.

Attraction Between An Electrified and An Unelectrified Body.

It will be seen from the foregoing that when a resinously electrified body, as A, be brought near an unelectrified body, as B, the stress in the elastic medium will be greater around A than around B, and of opposite character. That is, the medium around A is stressed outward, tending to make the cavity larger, while the medium around B is stressed inward, tending to make the cavity smaller. Since the total strain, and accordingly the potential energy due to these two stresses, would be decreased by bringing them together so that they could partly neutralize each other, there will be a force tending to drive A and B together.

The effect of surface curvature upon induction will be discussed later.

The Electric Condenser.

It has been found that when two conductors are placed very close together and one of them is connected to earth, the other will take a much greater electric charge under a given electric pressure than it will when at a distance from other conductors. In other words, its electric capacity has been increased by bringing an uninsulated conductor close to it.

To explain the action of the condenser let A and B, Fig. 6, represent two disc shaped cavities seen edgewise in an elastic block under the hydrostatic pressure of a fluid in a surrounding reservoir. Let B be connected by a tube to the fluid in the reservoir, while A is distended by pumping fluid into it until the pressure inside exceeds the external pressure.

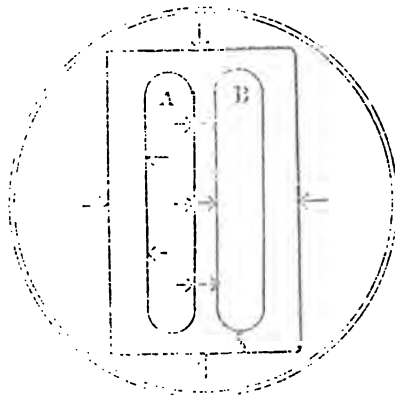


Fig. 6.

Since the pressure on the B side of the elastic sheet between A and B can never be greater than the external fluid pressure, this sheet must support the whole of the excess pressure on the A side by its own elasticity. If the sheet is very thin it will be greatly stretched in supporting a considerable pressure. The result is that the sheet becomes bulged toward B, and fluid is forced out of B almost as fast as it is forced into A. The capacity of A is correspondingly increased, and a much greater quantity of fluid can be pumped into A under a given pressure than could be if B were removed or were not in communication with the external reservoir. It will also be seen that the thinner the elastic membrane between A and B, the more it will be stretched in supporting a given pressure, and consequently the greater the capacity of A.

It is easy to see that if fluid were withdrawn from A, leaving the pressure over its surface less than the normal, a nearly corresponding amount of fluid would flow into B from the outside reservoir, the dividing membrane would be bulged toward A, and the decrease of pressure upon the surface of A would be less than if A stood alone.

Influence of the Elasticity of the Dielectric Upon the Capacity of a Condenser.

It has already been mentioned that the capacity of any insulated conductor depends upon the specific inductive capacity of the medium by which it is surrounded. The same is true of a condenser. If the dielectric sheet between A and B have less electric elasticity than the free ether, it will exert a smaller pressure upon the charge in A than would be exerted by the free ether, and it will accordingly require a greater charge in A to bring its electric pressure up to that of the source from which it is charged than it would if the dielectric were the free ether.

Bound Charge in a Condenser.

Regarding again the condenser in Fig. 6, we have seen that as the fluid is pumped into A the principal enlargement of the cavity A is on the side toward B. The thin membrane separating A and B becomes stretched and bulges toward B.

Suppose that after A has been very much distended toward B the cavity B is disconnected from the external reservoir and A is connected

to this reservoir instead. It is plain that some of the fluid in A will flow back into the reservoir, but this flow will cease when the pressure of the fluid on the B side of the membrane plus the pressure due to the contraction of the membrane becomes equal to the pressure in the reservoir. But the pressure on the B side of the membrane was only the reservoir pressure to begin with, and this will fall off as the membrane contracts toward A and the cavity B becomes larger. The result will be that only a part of the excess fluid in A will flow back into the reservoir before the pressure over its surface will equal that in the reservoir. When this condition has been reached, the pressure in B will be less than the reservoir pressure. If now A be disconnected from the reservoir and B connected with it instead, fluid will flow into B until the pressure on the B side of the membrane is equal to the pressure in the reservoir. The pressure on the A side of the membrane will then be greater than the reservoir pressure. Thus by alternately putting A and B into communication with the external reservoir a quantity of fluid will flow out of A each time and a quantity will enter B each time, until the pressure on both sides of the separating membrane becomes equal to the external fluid pressure.

The condition considered above is analogous to the condition known as the "bound charge" in a condenser. Thus if two conductors be used and B be joined to earth while A is insulated and charged with an excess of electrons, the dielectric separating A and B will be put into that state of internal stress which is known as the electric field. The electric pressure upon the B side of the dielectric partition can never become greater than the pressure of the earth's field, while the pressure upon the A side may be made very much greater. Accordingly, a quantity of electricity will be forced out of B and into the earth. If B be now insulated and A connected to earth, a quantity of electricity will flow from A to the earth until the electric pressure on the A side of the dielectric membrane becomes equal to the pressure of the earth's field. The electric pressure upon the B side of this membrane will then be less than that of the earth's field, and the dielectric will still be in a state of internal stress. Accordingly, if A and B are alternately one connected to earth while the other is insulated, A will give off electricity to the earth and B will acquire electricity from the earth until the electric pressure on both sides of the dielectric becomes equal to that of the earth's field.

Oscillatory Discharge of a Condenser.

In the case of the fluid condenser of Fig. 6, if after A had become much distended B were disconnected from the external reservoir and the separating membrane were suddenly punctured, the contraction of the walls of A would force the fluid into B with a sudden spurt, and the walls of B would be stretched before the fluid was brought to rest. As soon as the fluid had ceased to flow from A to B the walls of B would contract and spurt some of it back again into A, and the walls of A would be stretched to more than their normal tension. This would continue until the potential energy which was in the stretched walls of A in the beginning had all been transformed into kinetic energy in some form.

It will easily be seen that in the case of the elastic block which we have assumed these oscillations of the fluid would set up waves in the material of the block which would be transmitted in turn to the surrounding fluid. In the case of the unbounded ether, waves set up in this manner would continue to travel outward into space. It is in this manner that the well known Hertzian waves are set up in the ether.

Condition Inside a Charged Hollow Conductor.

It is a well known fact that an uncharged body wholly within a closed, charged, hollow conductor will take no charge from the inner surface. This fact has been regarded as evidence that there is no electricity on the inside walls of a closed, hollow conductor, no matter how great its charge. That this proof is not conclusive may be seen from the following considerations.

Let A, Fig. 7, represent a hollow conductor open at the top and resinously electrified. The excess of electrons in the conductor will exert an electric pressure upon the ether in contact with the surface, both on the outside and inside. If an uncharged, insulated conductor, as B, be lowered part way into A, the part that is within A will be in a field of greater electric pressure than the part outside. The electrons in B will accordingly be displaced toward the end which is outside of A. If B, while in this position, were allowed to come into contact with any part of A, it would take electrons from A, for the outer end of B is still in a region of less electrical pressure than the pressure over the surface of A. If, however, B be lowered into A until it is entirely inside and the opening in A be closed by a conducting cover, B

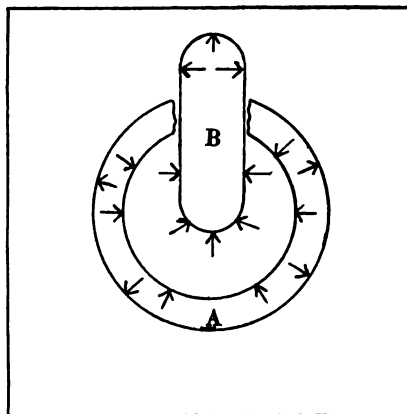


Fig. 7.

will be in a field of uniform electrical pressure exactly equal to the pressure over the inner surface of A. Since the electric stress in a dielectric follows the inverse square law, the pressure upon an electric charge anywhere within A will be equal in all directions, and there will be no reason why the electrons in B should be repelled to one side rather than another. Since the electric pressure is no greater upon a point in contact with A than upon any other point, B may come in contact with A without any of the electrons in A being forced into B. Thus an uncharged body within a closed, hollow conductor will take no charge from the inner surface of the conductor, no matter how great its charge may be.

The same thing will be true when the hollow conductor is vitreously electrified, except that the pressure within the hollow conductor is less than the pressure of the earth's field.

The Charged Body Inside a Hollow Conductor.

Since an uncharged body lowered into a charged hollow conductor can take no charge from the outer conductor, it follows that a charged body lowered into a hollow conductor and placed in metallic contact with it will lose its entire charge to the outer conductor, whether this be charged or uncharged. In the case of an uncharged, insulated hollow conductor the experimental facts are as follows:

If a charged body be placed inside an uncharged, hollow conductor which is insulated from other bodies, an electric field appears outside

the hollow conductor as if the charge were on the outer instead of the inner conductor. That is, the electric pressure is everywhere the same over the surface of the outer conductor as if it contained the electric charge. If the inside conductor be now put into metallic contact with the outer it will be discharged, but this will in no way affect the electric field around the outer conductor.

To explain these phenomena in terms of the fluid analogy, let A, Fig. 8, be a porous spherical cavity in an elastic body surrounding a central sphere, B, of the same elastic substance. Let C be a porous cavity in the central sphere B. Let the elastic body which contains the cavity A be under an external hydrostatic pressure. These conditions will correspond in our analogy to a hollow, spherical conductor, A, enclosing another conductor, C. Let A be filled with a fluid to the same pressure as the external hydrostatic pressure, and let C be filled with a fluid to a greater pressure than the external pressure.

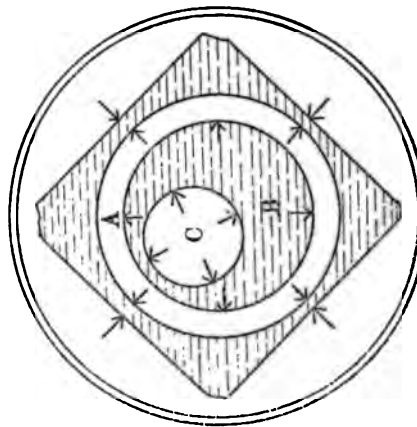


Fig. 8.

The elastic sphere B will then be stretched by the pressure of the fluid in C, and, if perfectly elastic, will transmit this pressure to the surrounding fluid in A, which will in turn transmit it to the elastic material around A. It is plain that if the material of the sphere B is incompressible, the outward pressure of the fluid over the surface of A will be the same as if the same excess of fluid had been forced into A instead of into C. To relieve this external pressure, A may be put into communication with the external fluid, when a quantity

of fluid equal to the quantity in C will escape, and the pressure over the outer surface of A will be merely the pressure of the external fluid. When in this condition the excess of pressure in C will be supported entirely by the stress in the elastic sphere B, which will be strained outward. If C be put into communication with A, the excess of fluid in C will flow into A, and the sphere B will again be under hydrostatic pressure. The medium around A will not be affected by this transfer, since there will be the same amount of solid material and the same quantity of fluid inside the outer surface of A that there was before the transfer was made.

This will be equally true if C be allowed to discharge into A before A is discharged. In this case the material of the sphere B is strained outward before C is discharged, and the pressure transmitted by it to the fluid in A causes an outward strain over the outer surface of A. When C is placed in communication with A the outward stress in B is changed to a hydrostatic pressure, thus decreasing the potential energy of strain in B without affecting the strain over the surface of A.

Electric Density.

From the law of inverse squares it appears that the electric pressure is transmitted by the ether without loss, so that if a series of concentric spheres be taken about an electric charge as a center the total pressure over the surface of each of these spheres will be the same. The pressure upon one square unit of the surface of these spheres will accordingly be inversely as the area of the surface. Thus if a sphere of one centimeter radius were charged until the electric pressure over its surface was one dyne per square centimeter, the electric pressure on a surface at a distance of one centimeter from the surface of this sphere would be $\frac{1}{4}$ dyne per square centimeter.

Let Fig. 9 represent two insulated spheres A and B, the former with a radius of four centimeters and the latter with a radius of one

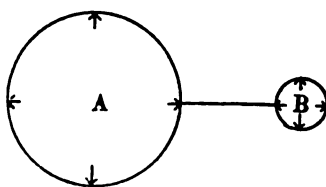


Fig. 9.

centimeter, connected by a conducting wire. Let both be charged until the electric pressure over their surfaces is p dynes per sq. cm. Since they are in communication this pressure will be the same over both. If a distant electroscope be provided with a long wire and the end of the wire be carried over their surfaces, the electroscope will indicate the same electric pressure no matter to what part of the system the wire is applied.

In going out from the two spheres the pressure will fall from p to $\frac{1}{4}p$ at radius distance from the surface of the sphere. Accordingly, around A the pressure falls off $\frac{3}{4}$ of p in a distance of four centimeters, while around B it falls off $\frac{3}{4}$ of p in a distance of one centimeter, or four times as rapidly.

Suppose an insulated sphere one centimeter in diameter to be put in contact with A. The electric pressure at the point of contact is p dynes per square centimeter tending to force electrons from A into the small sphere, while the pressure on the opposite side of the small sphere is $\frac{16}{25}$ of p . Electrons will enter the small sphere until the pressure is p over its entire surface.

If the small sphere be brought into contact with B instead of A, the pressure tending to force electrons into it will be the same as before, but the pressure over the side farthest from B will be only $\frac{1}{4}p$. It will accordingly take a greater charge to bring the pressure over the small sphere up to p than it did when in contact with A. The small sphere will accordingly take a greater charge from B than from A.

The fact that a small body will take a greater charge from that part of a conductor where the curvature is greater than from a part where it is less has given rise to the notion that the electricity is more condensed over the more curved parts of the surface. If, however, the small sphere were kept in a fixed position relative to A and B, and were then put into electric contact with each of them by means of a wire, it would take the same charge from B as from A.

Effect of Surface Curvature Upon the Compressional Stress in the Ether Around Charged, Curved Surfaces.

Another fact not heretofore taken into consideration, but which becomes important in this connection, is that for the same fluid pressure in two spheres of different radii the compressional pressure within the elastic medium surrounding the spheres will increase with the radius

of the sphere. We know that in the contraction of a curved surface film, as a soap film, the pressure exerted by the film normal to its surface increases with the curvature of the surface. Thus, if a large and a small soap bubble be joined, while the tension in the soap film is the same over both, the pressure of the film upon the contained air is greater in the smaller bubble, and the smaller bubble will accordingly contract into the larger one.

The capillary equation which expresses the pressure normal to its surface exerted by a contracting, spherical film is $P = 2T/R$, where P is the pressure of the film normal to its surface, T the tension of the surface film and R the radius of the sphere.

If instead of the two soap bubbles we had two spherical cavities in an elastic solid, and should pump a fluid into them until the solid around them was stretched, the pressure of the fluid upon the walls of the spherical cavities would be perpendicular to these walls and would be the same in both spheres, but the amount of stretching of the walls produced by this pressure would be different in the two cases. The capillary equation will apply in this case as well as in the case of the soap bubbles, except that the normal pressure P is a constant and the stretching force T varies inversely as the curvature. To express T in terms of the surface curvature we merely transform the capillary equation into the form $T = PR/2$, or T varies as R .

It is well known that a stress which stretches an elastic medium produces an equal compressing stress in all directions at right angles to the stretch. Hence if the walls of the larger spherical cavity are stretched more than the walls of the smaller, they are to the same degree compressed more in a direction normal to the surface of the sphere.

Accordingly, in the case of the two electrified spheres of Fig. 9, if a thin disc or proof plane be applied to the surface of first one and then the other, it will take a larger charge from B than from A, because, no matter how close it is applied to the two spheres, the pressure of the surrounding ether upon its enclosed fluid will be greater around A than around B. In the final limit, if the proof plane were applied very closely to the two surfaces it should take four times the charge from B that it would from A. Accordingly, when tested in this way the surface density of a charge on a system of conductors is said to be proportional to the curvature of the surface on which it rests.

Effect of Surface Curvature Upon Induction.

The compression in the medium surrounding a charged body is shown in another way by the fact that near a charged surface of which the curvature is not great a small body may take a much greater charge by induction than by contact with the charged surface. Thus if an insulated sphere one centimeter in diameter be held at a distance of one centimeter from a charged sphere ten centimeters in diameter and be touched by one end of a wire which is connected with the earth and again insulated, it will take a charge about four times as great as it will when touched to the larger sphere.

The fact that a body may take a greater charge by induction from a surface of less curvature than its own than it can take by conduction when touched to this surface was shown in some of Coulomb's experiments. Dr. Thomas Thomson* says that Coulomb found that when two spheres of different diameters were charged while in contact and then separated to a small distance, a charge opposite in character to that on the two spheres could be taken from the smaller sphere on the side toward the larger sphere. He found that the greater the difference in the diameter of the spheres the farther apart he could observe this effect. This, of course, means that if the smaller sphere while in this position had been touched to earth it would have taken a charge opposite in character to and greater in magnitude than the charge which it took while in contact with the larger sphere.

I have shown this phenomenon in a striking way as follows: A brass cylindrical vessel eighteen centimeters in diameter, insulated by placing it on a block of paraffin, was connected to a Leyden jar to increase its capacity and was charged from an electric machine. A cylindrical vessel seven centimeters in diameter was placed near the larger vessel and was connected to earth. An insulated sphere one centimeter in diameter was charged alternately by contact with the two cylinders and its charge tested by a gold leaf electroscope which had been calibrated. When the cylinders were four centimeters apart, the small sphere would take from seven to ten times the charge when touched to the small uninsulated cylinder on the side toward the large one than it would when touched to the side of the large charged cylinder. With a larger test sphere the charges taken from the charged and the uncharged cylinder became more nearly equal.

*Thomson, Heat and Electricity, p. 420.

I have not been able to determine experimentally a quantitative relation between the surface curvature of a charged conductor and the charge which may be induced upon another small conductor placed very near this surface. The sources of possible error in this determination are many, and I have been unable to avoid all of them in any experiment. I have, however, obtained roughly approximate results by several methods. In one case, the two metal cylinders referred to in the former experiment (the one eighteen cm. and the other seven cm. in diameter) were supported twenty cm. apart on paraffin blocks and were connected by a wire and to a charged Leyden jar at a distance of about a meter. For receiving the induced charge, a piece of thin sheet copper 2 cm. long and 1.6 cm. wide was cemented to two pieces of glass rod .4 cm. in diameter and 1.5 cm. long, which were placed parallel and at a distance apart of 1.5 cm. between their centers. A hard rubber handle 16 cm. long was also cemented to the copper plate. When the glass rods were placed against the side of one of the cylindrical vessels a small condenser was formed which had its greatest capacity when the glass rods were parallel to the axis of the cylinder. This is the position in which it was always placed while being charged by induction. While held in this position the copper plate was touched by the end of a copper wire connected to earth, and the induced charges were transferred to a gold leaf electroscope.

The capacity of the small condenser was somewhat greater over the smaller cylinder, as it came somewhat closer to the cylinder, but the determinations gave quite uniformly three charges induced by the larger cylinder equal to five charges induced by the smaller cylinder. This seemed to show beyond any question the influence of the surface curvature of the cylinders upon induction, as otherwise the larger charge should have been induced by the smaller cylinder.

Field Strength and Curvature of Surface.

The strength of an electric field is measured by the force which acts on a unit charge when brought into that field. Since the electric stress in the ether falls off more rapidly around a surface of greater curvature, a small, charged body brought near the charged conductors A and B in Fig. 9 would when near their surfaces be more strongly attracted or repelled by B than by A, since the difference of electrical pressure over its opposite faces would be greater near B than near A.

Electric Discharge Through Air.

When the electric field between two conductors in air becomes strong enough, a spark discharge will take place between them and the conductors will be discharged. This discharge is due principally to the molecules of the air between the conductors being separated into positively and negatively electrified ions and these ions being driven by the electrical field to the conductor having a charge opposite to their own.

What is true of air is also true of other dielectrics. Since their molecules are made up of positively and negatively electrified particles, when the electrical field becomes strong enough their molecules are dissociated and the conductors are discharged by their electrified ions. It is believed that in a perfect vacuum no discharge would take place, even under very great electric pressure.

Electric Discharge From Points.

It has been seen that for the same electric pressure the electric field is stronger over a surface of greater curvature than over a surface of less curvature. Thus in the case of the two spheres in Fig. 9, two small, oppositely electrified conductors would be pulled apart with a greater force if near B than if near A. If B were made smaller and smaller, this separating force very near its surface would become greater and greater. If B were reduced to a fine point, the electrical field very close to this point would be very strong, and might separate the molecules of the surrounding dielectric into their positive and negative ions. If the point were positively charged the negative ions of the molecules would be attracted to it, and would either combine with the metal of the point or give off electrons to the point. In either case the point would be discharged by the surrounding dielectric.

It is well known that a conductor provided with points cannot retain even a very weak charge in air.

Metallic Conductivity.

It is now understood that in the flow of an electric current along a wire the electrons are the only moving particles. There is no proof that the positive parts of the atoms take any part in the transmission of the current. The electrons necessarily move in the opposite direction

to the current as conventionally defined, since the direction of motion of the hypothetical positive electricity was assumed as the direction of the current.

There are apparently two possibilities as regards the relation of the conducting electrons to the atoms or molecules of the conductor. They may be electrons which are more or less closely attached to the atoms of the conductor, or the current may be carried by free electrons which move like a wind through a porous body. Sir J. J. Thomson* has discussed both possibilities on the basis of certain assumptions which he has made in both cases, but finds no particular advantage in one assumption over the other, though he seems to have preferred the second alternative. It seems exceedingly probable for reasons which have been given in discussing the earth's field that bodies in the normal electrical condition of the earth do contain an excess of electrons above the number necessary to combine with the positive atoms in their normal condition. We have seen, however, that any great excess of electrons above the number necessary to combine and form the atoms as they are now constituted would cause the positive atoms to take up a greater number. Thus, if all the atoms and molecules in the earth contained just a sufficient number of electrons to make the electrical pressure over their surfaces the average electrical pressure over the earth, they would all be electrically neutral. If, now, the earth could acquire a considerable number of free electrons, so as to increase the electrical pressure over its surface, its atoms and molecules would become electropositive and would require additional electrons to render them electrically neutral. It would accordingly seem that the number of uncombined electrons in the earth must be small as compared with the whole number of atoms or molecules.

It has been shown that the resistance to the passage of an electric current through a conductor is mostly, if not entirely, due to the ether between the atoms of the body. Experiments made by Dewar and Fleming† on the electrical resistance of pure metals and alloys at very low temperatures indicate that the pure metals, with the exception of Bismuth, would become almost perfect conductors at a temperature near absolute zero. Since the absolute zero is supposed to be the point where all molecular vibration would cease, it seems extremely probable that at this point the atoms of bodies would be in permanent contact with each other, and no longer separated by a film

*Thomson, *The Corpuscular Theory of Matter*, Chapter IV.

†Dewar and Fleming, *Phil. Mag.* xxxiv, 326, Oct., '92, and xxxvi, 271, Sept., '93.

of ether. If under these conditions the metals would offer no resistance to the passage of electrons, while the electrons would have to pass through or between more atoms in a given distance than before, it seems certain that the atoms themselves offer no resistance to the passage of electrons. The whole resistance accordingly seems to be due to the ether films which surround the atoms.

It necessarily follows from the preceding discussion that if the atoms of a conductor are surrounded by ether whose electrical elasticity is greater than that of the ether inside the atoms, electrons entering an atom will be hindered in escaping from it, just as electrons are hindered in escaping from a conductor, by the greater pressure exerted upon an electron at the surface of the atom by the outside than by the inside ether. This would seem to make it probable that the excess of electrons in a resinously charged body are usually associated with the atoms of the body, and are not free bodies like the molecules of a gas.

Since this view is contrary to the one which seems to be favored by Sir J. J. Thomson, and which seems to have been adopted by most recent writers on the subject, it may be well to give some of the arguments in its favor which seem to have been generally overlooked.

Bearing of Photoelectric Phenomena on Theories of Conduction.

It has long been known that some metals when negatively charged or when unelectrified give off electricity when illuminated by ultra-violet radiation. This method of producing free electrons is now quite commonly used. The metal most frequently used for this purpose is zinc, but the more electropositive the metal is in the Voltaic series the more readily it parts with its negative charge under the action of the ultra-violet light.

Elster and Geitel* determined the order of photoelectric sensitiveness of the metals, and also found that the effect was associated with the absorption of ultra-violet light by the metals. It is also well known that the arc spectra of these metals contain many ultra-violet lines.

This seems to indicate that the electrons are set oscillating by the ultra-violet light before they are thrown off from the metal, and this hypothesis is strengthened by work done in 1909 by Kunz†. Kunz

*Elster and Geitel, *Ann. d. Phys.*, xxxviii, 404, 497, 1889; xli, 161, 1890; xlii, 564, 1891.

†Kunz, *Phys. Rev.*, xxix, 174, Aug., 1909.

showed that the intensity of the discharge of electrons from sodium-potassium alloys under the action of ultra-violet radiation varied with the angle of polarization of the incident radiation; that it was greatest when the radiation was polarized at right angles to the plane of incidence, that is, when the electric component of the radiation was approximately normal to the metal surface; and that the electrical discharge was least when the electrical component of the incident radiation was parallel to the surface of the metal. This makes it seem that the electrons which escape from the metal surface are those which have been set in vibration perpendicular to that surface.

In later papers* Kunz showed that the velocity of the emitted electrons was independent of the intensity of the incident light, and that their kinetic energy was proportional to the frequency of the incident light. This latter fact has also been shown by others. This shows that the electrons which are set free by ultra-violet light must be in a state of periodic vibration before they leave the metal, and consequently that they are associated with definite atoms, and are not free bodies like gas molecules.

The converse of the photoelectric phenomenon was shown by the present writer first in 1892 and later†. It was found that if a metallic conductor were attached to the cathode of an induction coil while a spark was passed between the terminals, ultra-violet light was sent off from the metal of the conductor. Also, that contact with the cathode was not necessary, but that an insulated conductor placed between the plates of a condenser which were attached across the spark gap of an induction coil while a spark was passed would likewise send out ultra-violet light. Even a hollow metal conductor attached to one of the wires of the spark gap, preferably the cathode, will send off ultra-violet light from its inner surface, and photographs were printed inside a closed tin box by the ultra-violet light sent off by the sides of the box. The wave lengths of the ultra-violet light sent off by different conductors were roughly measured and found to be different for different metals. The same phenomenon has since been examined in this laboratory by Miss Shirley Hyatt for a number of salts and other substances, and so far as they have been tested, only substances which show the photoelectric effect are capable of giving off ultra-violet radiation in the alternating condenser field.

*Kunz, Phys. Rev., xxix, 226, Sept., 1909, and xxxi, 536, Nov., 1910.

†Sanford, Phys. Rev., ii, 59, 1893; xvii, 441, 1903; xviii, 366, 1904; xxi, 343, 1905.

It would seem that in the case of an insulated conductor in the condenser field the electrons on the surface are set in oscillation by the rapid change in direction of the electric field between the plates, and that these oscillations set up the ultra-violet waves in the surrounding ether. This could not happen unless these electrons were part of an atomic system and had a natural and rapid period of oscillation. It accordingly seems certain that the electrons which are discharged from metals by ultra-violet radiation, as well as those which are capable of setting up ultra-violet radiations around the conductors, are, while in the metals, parts of atomic systems. This being the case, it follows that if these electrons pass along a metallic conductor they do so by means of discharges from one atom to another through the intervening ether films. Since this ether still possesses some electric elasticity within conductors, the successive discharges between two atoms will necessarily be of a periodic character, somewhat as between two conductors in air, except that in the conductor the discharge will be principally in one direction.

Consider the case of two small spheres A and B between two large conductors C and D, as in Fig. 10, one of which is kept negatively and

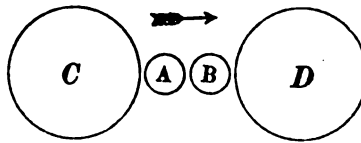


Fig. 10.

the other positively electrified. Every time a discharge occurs from C to A the ether around A is suddenly stretched, and in its recovery it exerts an increased electrical pressure over A which tends to force the charge onward into B. In a similar manner B passes the charge on to D. The relatively small change in electric pressure over C and D will cause but little oscillation in their electric fields, and consequently but little, if any, of the charge will be forced back from A to C. Also, A in recovering after it has forced its charge onward into B will receive its next charge from C rather than by oscillation backward from B, for A is in an electric field where the pressure is already greater than around B. The discharge along a single line of atoms will accordingly be rather in the nature of periodic flights of one or more electrons in one direction than of the oscillations which accompany an electric spark in air.

This is virtually the method of conduction assumed by Sir Oliver Lodge* and called by him the "fire bucket method." He says in discussing conduction in metals that the atoms, not being susceptible of locomotion, "can only pass electrons on from hand to hand; oscillating a little in one direction to receive them, and in another direction to deliver them up, and so getting thrown gradually into the state of vibration which we call heat."

Surface Currents Along Metallic Conductors.

Since the electric elasticity of the ether between the atoms is very slight, the oscillations of a discharging atom will be relatively slow. The electrons will accordingly be passed from one atom to another much more slowly than in the case of the electric spark in air. Over the surface of a conductor there will necessarily be a surface film of atoms in which the ether elasticity changes from that of the surrounding dielectric to that within the interior of the conductor. Since the average electric elasticity of the ether in this surface film is greater than the electric elasticity of the internal ether, when a current is being set up in a conductor the electrons will be passed along more rapidly on the surface than in the interior. For this reason an alternating current of high frequency is confined principally to the surface of the conductor. It is very probable that the carrying power of a conductor for such currents will be different in dielectrics of different specific inductive capacity.

Influence of Surrounding Dielectric Upon Conductivity.

It seems probable, also, that after a current is established in a conductor the influence of this surface film may still be felt, especially in fine wires, where the surface film becomes a measurable part of the cross section of the conductor. In this event, the carrying capacity of a fine wire even for direct currents might vary in different dielectrics. This phenomenon was observed by the writer in 1891† and was verified by Grimaldi and Platania at the University of Catania in 1895‡.

*Lodge, *Electrons*, p. 107.

†Sanford, *Some Observations Upon the Conductivity of a Copper Wire in Various Dielectrics*. Leland Stanford, Jr., Publications, 1892. See also *Phil. Mag.* xxxv, 65, 1893; *Phys. Rev.* iii, 161, 1895.

‡Sulla Resistenza Elettrica Dei Metalli Nei Diversi Dielettrica. Memoria di Giovan Pietro Grimaldi e Giovanni Platania, Catania, 1895.

In regard to this phenomenon the conclusions of different observers have been conflicting, and in my own observations certain wires failed entirely to show the effect. This, I think, is due to the formation of a dielectric film over the surface of the wires in some cases, which film does not change when the dielectric surrounding the wire is changed.

Heating Effect of Current.

The periodic discharges of electricity from atom to atom as assumed above would cause oscillations of the atoms, themselves. When two contiguous atoms have unlike charges they attract each other, when like charges, they repel each other. Accordingly, each discharge will produce a vibration of the atoms. Since the distance through which the atoms of a conductor can vibrate is fixed within narrow limits, and since there must be one vibration for each discharge, the velocity of the vibrating atoms will vary as the rate of discharge between them, and accordingly as the current intensity. The energy of atomic vibration will accordingly vary as the square of the current intensity.

Ether Radiation About a Current.

Since each atomic discharge causes at least one stretching and one contraction (in terms of our analogy) of the ether about the atom, the ether about a current flowing in a conductor will be in a continuous state of periodic agitation. These periodic agitations will set up waves in the internal ether which may spread to the ether surrounding the conductor. On account of the relatively slow rate of discharge due to the slight electric elasticity of the ether surrounding the atoms, these waves will be of lower frequency than light waves. They are probably associated in some way with the magnetic field about a current.

Relation of Heat Conductivity to Electrical Conductivity.

Since atoms are built up of oppositely electrified particles, unless the total charges of both kinds are equal and concentrically arranged, each atom must have an external electrical field. It will be shown later that the attraction due to these electrical fields between atoms constitutes cohesion.

If an atom be set oscillating, the electrical field between it and surrounding atoms will vary periodically. Accordingly if the atoms

at one end of a conductor be thrown into oscillation, these oscillations will be transmitted to all the atoms in the conductor by the periodic variations of the electric fields between them. The greater the electric elasticity of the internal ether and the closer the atoms are together the faster this disturbance will spread through the conductor. The same conditions in the surrounding ether which would make an atom pass its charge along quickly will make it transfer its energy of vibration rapidly. Good conductors of electricity should accordingly be good conductors of heat.

Contact Electromotive Force.

It was shown by Volta, in 1801, that when two plates, one of zinc and one of copper, provided with insulating handles are brought into contact with their faces parallel to each other and then separated, the zinc becomes vitreously and the copper resinously electrified. Volta also showed the same conditions to hold with a number of other metals, and he arranged a series of metals in which each metal becomes positively electrified when brought into contact with one below it in the series.

Volta's experiments have been frequently repeated, and several series of careful measurements of contact electromotive force have been made, notably by Lord Kelvin and his students and by Pellat. It has also been shown by Righi and by Majorana* that "Whenever two dissimilar conductors after having been discharged to earth approach each other without being brought into contact, they acquire free electric charges which may be removed by any conductor (not an electrolyte) whether put to earth or insulated, but in the latter case the conductor must be of large capacity relatively to that of the disks experimented upon.

"These *approach charges* are opposite in sign to those obtained in the ordinary Volta experiment; so that zinc brought near to copper is charged negatively, and copper brought near to zinc becomes positively charged."

Volta believed this contact electromotive force to be between the metals, themselves, and to be a true property of the metals. Others have held to the theory that the observed electromotive force is due to chemical action taking place between the metal and the surrounding medium, probably the oxygen of the air. The modern chemical expla-

*Q. Majorana, Phil. Mag. xlviii, 241 and 255, Sept., 1899.

nation is usually somewhat as follows: The metals are covered by an adsorbed water film. This water film contains oxygen from the air, and consequently oxidizes the surface of the metal, making a solution of the metallic oxid. This, when dissolved in water, dissociates into positive (metallic) ions and negative hydroxid ions. The negative ions have the greater diffusion velocities in the solution, and hence move away from the plate faster than the positive ions. Hence when two metals are placed in contact the more oxidizable metals lose their negative ions faster than the nobler metals and consequently become more positively electrified.*

This explanation fails utterly to account for the "approach charges" referred to by Majorana. The total possible distance of separation of the two kinds of charged ions in the electrolyte, assuming only one of them to diffuse into the liquid at all, would be less than half the thickness of the adsorbed water film. That is, if the metallic ions did not diffuse into the water at all, and if their attraction for the hydroxid ions were zero, after they had become uniformly diffused throughout the liquid film their average distance from the metallic ions would be half the thickness of the liquid film. Of course, such a supposition as this is untenable, and their average distance from the positive ions must be very much less than this. It would accordingly be inconceivable that the electric fields which have been observed between metal plates could be produced in this way, even if the surface layer of ions were positive over one metal and negative over the other. But from the fundamental assumptions of the theory the surface ions over both plates are negative. The presence of each would accordingly weaken the electric field of the other.

Not only does the above hypothesis fail to explain the phenomena for which it was invented, but the conditions assumed in it seem to have been excluded in experiments made by Mr. J. Erskine-Murray† and Mr. F. S. Spiers‡. Erskine-Murray found that plates whose surfaces had been prepared by filing or scraping under melted paraffin, or by melting the metal and pressing between glass plates kept all the time under melted paraffin, and whose surfaces had never been exposed to the air, gave sensibly the same contact difference as when prepared in air. He also found the contact difference of potential to vary with the temperature, each metal having its own temperature coefficient of

*See Knoblauch, *Zeit. für phys. Chem.*, xxxix, 225.

†Erskine-Murray, *Phil. Mag.*, xlv, 398-432, 1898.

‡Spiers, *Phil. Mag.*, xlix, 70, 1900.

variation, but all varying in such a way as to suggest that at a low temperature (somewhere below -200° C.) all contact differences would disappear.*

Spiers found that iron and platinum plates which had been heated red hot for some time in a hydrogen atmosphere and in a very low vacuum still showed a contact difference of potential of .6 volt, but in this case the iron was negative to platinum while under ordinary circumstances it is positive. Mr. Spiers argues the impossibility of removing the last trace of oxygen from the space surrounding the metals, but certainly the adsorbed water film must have been removed in both his experiments and those of Erskine-Murray.

As regards the existence of the phenomenon under consideration there can be no question. The difference of opinion is upon the adequacy of Volta's explanation. From the point of view adopted in this discussion, the contact difference of electric potential would follow from the fundamental assumptions.

Thus, electric charges move about within conductors or from one conductor to another as a result of an ether pressure upon their electrons. This pressure, which is due to the electric elasticity of the ether, is less in all bodies than in the free ether, and is less in conductors than in other bodies. We have seen, however, that the atoms of conductors are apparently surrounded by ether films, and that the electrons are held to the positive parts of the atoms by the electric pressure of these ether films. Hence all bodies, even conductors, have some electric elasticity in their internal ether.

When electrons are forced into a conductor from the earth, which serves as a great reservoir in which the electric fluid is stored under pressure, they are resisted by the electric pressure of the earth's field over the surface of the conductor, and by the electric elasticity of the ether films surrounding the atoms within the conductor. The greater the ether elasticity between the atoms of the conductor, the larger the part of the electric pressure of the fluid in the earth it will support. The less the electric elasticity of the ether within a conductor, the greater the pressure which the charge it takes from the earth will exert upon the ether in the surrounding dielectric. If two conductors have slightly different internal ether elasticities, the charges which they take from the earth will exert slightly different pressures upon the ether surrounding them.

*The significance of this observation will appear, if it be shown that the contact potential difference depends upon the elasticity of the inter-atomic ether, since at absolute zero the atoms may be assumed to be in contact.

If two such conductors be insulated from the earth and brought near together, since the electrons within one exert a greater pressure upon the surrounding ether than do those within the other, there will be an electric field between them. Since the ether pressure is greater over the surface of the one having the smaller internal ether elasticity (hence the greater specific inductive capacity) this one will be negatively electrified relatively to the other. If the conductors are brought into contact with each other, since the charges in the two bodies previously exerted different pressures upon the surrounding ether, their reciprocal pressures upon the surface of contact will be different. There will be an unbalanced pressure across this surface, and electricity will flow from the one which exerted the greater pressure upon the surrounding ether into the one which exerted the smaller pressure. This one, if insulated from the other and connected to the earth, will then be found to have a resinous charge with reference to the earth.

To produce the corresponding phenomenon with material bodies, let A and B, as in Fig. 11, represent two porous cavities in a block of India rubber, and let the tissue separating the porous spaces be thicker

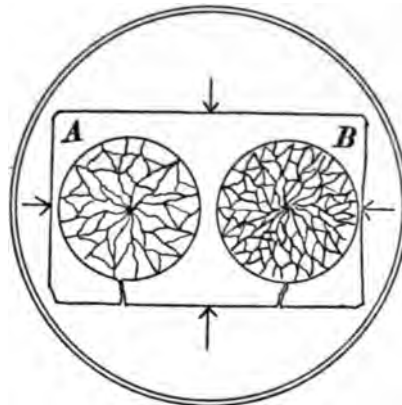


Fig. 11.

or more elastic in B than in A. Let both cavities be put into communication with the same reservoir containing a fluid under pressure. When the fluid is forced into both cavities its pressure will be supported partly by the elasticity of the rubber tissue surrounding the porous spaces inside the main cavities, and partly by the surrounding rubber. Since this porous tissue has a higher elasticity in B than in A, the rubber surrounding B will be stretched less than that surrounding A.

If the two cavities be disconnected from the reservoir and brought very near together, there will be a falling off from A to B in the internal stress of the rubber immediately between them. This corresponds to the falling off of electric stress in an electric field, and is analogous to the Righi-Majorana phenomenon. If while still very close together the two cavities be put into communication with each other, fluid will flow from A to B until the elastic strain is equalized over both sides of the elastic membrane separating them. This corresponds to the Volta phenomenon.

If the porous cavities are in the shape of flat discs and their plane faces are brought close together the region of varying strain between them will be much greater than if they are spherical, and accordingly a much greater quantity of fluid must flow from the one to the other before this strain becomes hydrostatic.

This view of the phenomenon would make the Volta contact series in metals the same as the dielectric series. That is, the conductor around which the electric fluid received from the earth exerts the greatest pressure is the one having the least internal electric elasticity and the greatest specific inductive capacity. It is also the one which would lose electrons when insulated from the earth and brought into contact with a conductor having a lower specific inductive capacity.

This law has already been observed for non-metallic substances. In 1898 Coehn* announced that for non-metallic substances those having a higher dielectric constant become positively charged when brought into contact with substances having a lower dielectric constant. Consequently the explanation of contact electromotive force here given will apply equally well to conductors and non-conductors.

Contact Electromotive Force and Cohesion.

We have seen that the parts of the atoms in material bodies are held together by electrical forces resulting from the electrical elasticity of the ether surrounding these atoms. The same must be true of the forces which hold together the individual atoms in a solid or a liquid. That is, the electropositive sub-atoms must be held together by the mutual attraction of two or more of them for the same electron or electrons. This attraction when it holds together the atoms of a gas molecule is called chemical affinity, but when it holds together the atoms or molecules of a solid or liquid is generally called cohesion.

*Coehn, Wied. Ann., lxiv, 217, 1898.

Since cohesion is the attraction between positively and negatively electrified particles it must depend, among other things, upon the electric elasticity of the ether surrounding these particles. In bodies of similar atomic structure, as in the pure metals, cohesion should be greater when the internal elasticity of the ether is greater, and consequently when the specific inductive capacity is less.

We have already seen that from our argument the greater the internal elasticity of the ether the more electronegative the metal should be in the Voltaic series. From what has been said regarding cohesion, it would seem that the cohesion series of the metals should be the same as the Voltaic series, the metals with least cohesion being the most electropositive. That this law seems to hold with very few exceptions was shown by the present writer in a paper prepared for the meeting of February, 1908, of the American Physical Society.* The following table is taken from this paper.

VOLTAIC SERIES	Compressi- bility $\times 10^6$	Melting Point	Expansion Coefficient	Hardness
Caesium	61	26.5		.2
Rubidium	40	38.5		.3
Potassium	31.5	58		.5
Sodium	15.5	95	.000072	.4
Lithium	8.8	180		.6
Zinc	1.5	419	.000029	2.5
Lead	2.2	330	.000028	1.5
Tin	1.67	230	.000022	1.8
Iron .....	.38	1500	.000012	4.5
Silver .....	.82	950	.000019	2.5—3
Copper .....	.54	1054	.000017	2.5—3
Gold .....	.47	1035	.000015	2.5—3
Platinum .....	.21	1780	.000009	4.3
Carbon .....	.5	unmelted	.000005	10.

*Sanford, Phys. Rev. xxvi, 410, 1908.

Since there are no direct data on the cohesion of the metals, I have attempted to relate the Voltaic series to the compressibility, the melting point, the expansion coefficient and the hardness, using the metals whose positions in the Voltaic series are fairly well known. The data on the melting point, the expansion coefficient and the hardness are taken from Landolt and Boernstein's Tables; the compressibilities are taken from an article by Professor T. W. Richards, in *Zeitschrift fuer physikalische Chemie*, LXI, 196, Dec., 1907. Since writing the article referred to above, I have found in *Beiblaetter XIV*, 705, 1901, a reference to an article in Russian by N. Hesehus, in which he has related the contact electromotive force of metals to the hardness on experimental grounds. This article was unknown to me when I wrote the paper for the American Physical Society.

As will be seen from the table, iron seems to form the one important exception to the law. Its other properties would make it seem to belong just above platinum in the Voltaic series. In this connection it is interesting to recall the fact that Spiers found iron, when heated a long time in an atmosphere of hydrogen to get rid of oxidation, to be electronegative to a platinum plate which had been heated with it in the hydrogen. It is not likely that the true electromotive force between iron and platinum was determined by this experiment, since both metals absorb hydrogen readily when heated, so that their specific inductive capacity was probably affected by the dissolved hydrogen, but it makes it seem probable that the two metals belong much closer together in the Voltaic series than previous experiments have indicated.

Zinc also seems to be out of place in the series as indicated by all the properties considered except its expansion coefficient. In some of the determinations which have been made zinc falls below lead in the series, but its compressibility and its melting point would seem to place it between tin and silver. Since Erskine-Murray, in the paper previously referred to, found zinc and lead to have positive temperature coefficients and tin to have a negative temperature coefficient of electromotive force, at a lower temperature tin would come above both lead and zinc in the series.

Since the publication of the above table a reference in *Science Abstracts*, Section A, No. 139, July 26, 1909, Abstract 1158, states that I. Traube "has recently shown that if, by means of van der Waals' equation the approximate surface tensions, a/v^2 , are calculated, it is found

that the numbers and the electric potential-difference of the metals, and therefore the Voltaic series, corresponds extremely closely." Since the surface tension is definitely dependent upon cohesion, this furnishes another strong proof of the hypothesis that both are dependent upon the electric elasticity of the internal ether.

Temperature Coefficient of the Volta Electromotive Force.

Erskine-Murray, in the paper already cited,* has given a few determinations of the variation of the Volta electromotive force with temperature. He found that the metals aluminium, zinc and lead become more positive as the temperature increases while iron and gold become more negative. In silver, copper and tin the change is very slight.

Since from our hypothesis the position of the metal in the Voltaic series depends upon the specific inductive capacity of its internal ether, this would indicate that in aluminium, zinc and lead the specific inductive capacity is increased by an increase of temperature, while in iron and gold it is decreased. Since the specific inductive capacity of a metal is apparently not measurable, it is impossible to verify or disprove this hypothesis by direct experiment.

The Seebeck, Thomson and Peltier Effects.

Other phenomena which are apparently associated with the change of electromotive force with temperature are the Seebeck effect, the Thomson effect and the Peltier effect. Thus if a circuit be composed of two metals which occupy different positions in the Voltaic series electrons will flow from one metal to the other at both junctions until the Volta difference of potential is neutralized by an excess of electrons in one metal and a deficiency in the other. There is then no reason why electrons should flow in one direction more than in the other at either junction. If, however, one junction be warmer than the other and if one metal have a different temperature coefficient of electromotive force from the other the pressure upon the electrons will be no longer balanced at the two junctions and a Seebeck current will flow around the circuit. This current will flow in a direction such that the electrons acquire energy from the atoms at the hot junction and return it again

*Erskine-Murray, Phil. Mag., xlv, 398-432, 1898.

to the atoms at the cold junction, but the mechanism by means of which this transfer of energy is accomplished is not understood. From the hypothesis advanced in this paper, atoms surrounded by ether having a higher electric elasticity should discharge their electrons at higher velocities than atoms surrounded by ether having a lower electric elasticity. Accordingly, when atoms of the former kind discharge their electrons into atoms of the latter kind, the electrons should enter the atoms with a higher velocity than they would have on leaving them, and should accordingly give some of their kinetic energy to the atoms. It is difficult to see in what other way an energy exchange could take place between the atoms and electrons. Too little is known at the present time, however, concerning the temperature coefficient of the Volta effect and the magnitude of the Seebeck, Peltier and Thomson effects in the same metals to explain the phenomena on the above hypothesis or on any other grounds.

The Thomson effect would seem to follow directly from the change in the Volta electromotive force with change of temperature, but the question of the exchange of energy between the electrons and atoms offers the same difficulty of explanation here as in the Seebeck and Peltier effects.

ELECTRIC CURRENTS.

Electrolysis.

We have seen that cohesion between the atoms of a metal is an electric force. The only kind of electric attraction we know is the attraction between opposite electrical charges. The only negative electrical charges known to us are the electrons. Hence cohesion must be the attraction between positive sub-atoms and electrons. Such an attraction would not hold atoms together unless two or more positive sub-atoms were attracted by the same electron. Hence cohesion or affinity must consist of the mutual attraction of two or more positive sub-atoms for the same electron or electrons.

Electric attraction varies inversely as the specific inductive capacity of the medium around and between the charges. Since the specific inductive capacity of the surface film of metals must be less than that of the interior, cohesion must be greater between the surface atoms than between those of the interior.

This cohesion of the surface film must vary with the electric elasticity of the surrounding ether, consequently when a metal is immersed in a medium of high specific inductive capacity the cohesion between its surface atoms must be diminished. The specific inductive capacity of water is 80, hence when a metal is immersed in water the electric pressure which holds the surface atoms to the metal is $1/80$ as great as before. If with this weakening of the surface cohesion there is combined a cohesion between the positive sub-atoms of the metal and the water molecules, or between the positive sub-atoms and negatively charged ions contained in the water, the positive sub-atoms of the metal may break away and escape into the water.

The mere weakening of the surface cohesion by water is not alone sufficient to dissolve metals extensively, but the specific inductive capacity of mercury is so great that many metals go into solution in it. When water contains negatively charged ions which attach themselves to the positive sub-atoms of the metal and in that way weaken their attraction for the electrons in the metal, most metals may go into solution in water.

What is true of the surface atoms of metals is also true of other solids. In many solids the chemical molecules are held together by much weaker forces than are the positive sub-atoms and electrons in metals, and these substances frequently go into solution in water. If the substance be one having a lower specific inductive capacity than water, its chemical molecules are held together by weaker forces when dissolved in water than they were before solution, hence many molecules which are stable in the solid or liquid form or as gas molecules become unstable when dissolved in water, and dissociate into positively and negatively electrified sub-molecules, called ions. Alcohol, with a specific inductive capacity of 25 ranks next to water, but far below it, as a general solvent.

This molecular dissociation in water solutions is especially marked in mineral acids, bases and salts. Most mineral acids seem to be made up of molecules consisting of one or more electropositive hydrogen sub-atoms held to another positive sub-atom or group of atoms by their mutual attractions for one or more electrons. When these complex molecules are dissolved in water, the electric attraction between their positive and negative parts is so weakened that the hydrogen sub-atoms break away from the connecting electrons and become positive ions, while the remaining positive sub-atom or group of atoms retains the

connecting electron or electrons and with them constitute the negative ions.

In all the common acids the weakest attraction seems to be between the hydrogen sub-atoms and the connecting electrons. This must mean that hydrogen is less strongly electropositive than the other atom or group of atoms with which it is associated in the molecule. Thus if the positive sub-atoms be themselves made up of positive and negative particles, the charges of these particles must be more nearly balanced in hydrogen than in the other sub-atoms with which it is associated in acids. When metals go into solution their ions, being more electropositive than the hydrogen ions already in the solution, form more stable combinations with the electronegative ions of the solution and tend to permanently displace the hydrogen sub-atoms. This indicates that the positive charges of the metallic sub-atoms are not exactly equal to, nor exact multiples of, the hydrogen sub-atom, as has been assumed in all modern electrical theory.*

Those metals in which cohesion has been shown to be weakest are the ones which most easily give off their positive sub-atoms to the electrolytic solution. Since the electrons which were associated with these positive sub-atoms are left behind in the metal, the undissolved part of the metal becomes more and more electronegative as its positive ions escape. If the metal be insulated, it may become sufficiently electronegative to hold its positive sub-atoms from further escaping into the solution. Since the more electropositive metals give off their positive sub-atoms faster than the others, they become electronegative in the solution faster than the others. Accordingly, the weaker the cohesion in a metal the more electropositive it is in the Voltaic series and the more electronegative it becomes in the electrolytic series.

The Voltaic Cell.

If plates of two metals, as zinc and copper, be placed in an acid water solution both give off positive sub-atoms to the solution. Since cohesion is greater in copper than in zinc, zinc dissolves more rapidly than copper, and hence becomes more rapidly electronegative. If the two metals be connected by a wire some of the electrons set free in the zinc will flow along this wire to the copper, thus keeping both metals at

*The question of the relative magnitude of atomic charges will be discussed at greater length later.

the same electrical potential. Copper will accordingly become strongly enough electronegative to hold its positive sub-atoms before the zinc will. As the zinc continues to give off its positive sub-atoms to the solution and its negative electrons to the copper, the latter soon acquires a sufficient negative charge to attract to it the positive ions of the solution. If these are metallic ions, they are deposited upon the copper plate, combining with some of the electrons in the metal and making it less electronegative. If they are hydrogen ions, they are attracted to the plate and probably enter it, after which two of them combine with one or more electrons and, being no longer held by the plate, escape as hydrogen gas molecules.

The zinc will accordingly continue to give off positive sub-atoms to the solution and negative electrons to the copper, while the copper receives negative electrons from the zinc and positive ions from the solution. The electric current in the solution will be due, on the whole, to the drifting of positive ions from the zinc to the copper, while the current in the connecting wire will be due to the drifting of electrons from zinc to copper. Dissociation will be continually taking place at the surface of the zinc and recombination will be taking place at the copper surface. The source of energy in the Daniell's cell is accordingly the difference of cohesion in zinc and copper. Both the positive sub-atoms and the negative electrons are passing from a region of lower into one of higher cohesion, and in so doing they are losing potential energy and gaining kinetic energy.

It follows from this point of view that a metal placed in a liquid of higher specific inductive capacity will become electronegative to the same metal in a liquid of lower specific inductive capacity. This has been shown experimentally by van Deventer and van Lummel,* though they offered a different interpretation of the phenomenon which they observed. By placing one piece cut from a rod of a given metal, as zinc, in a solution of sulphuric acid in water and another piece of the same rod in a solution of sulphuric acid in water and alcohol which was floated on the top of the water solution, the piece of metal in the alcohol became the positive pole of a voltaic cell, taking the place of copper in the Daniell's cell. In this experiment the piece of metal in the water solution gave off its positive sub-atoms faster than the piece in the alcohol solution, evidently on account of the higher specific inductive capacity of the water. By using two metals of nearly the same contact electromotive force, Messrs. van Deventer and van Lummel were able

*Van Deventer and van Lummel, *Zeit. phys. Chem.*, lxi, 136, 1909.

to invert the electrolytic polarity of several pairs of metals by putting the more electropositive metal (electropositive in the Voltaic series) in the alcohol solution.

Charges of Electrolytic Ions.

It has been suggested in the preceding pages that the positive sub-atoms do not carry charges which are exact multiples of the electronic charge. This is contrary to the general assumptions of modern electrical theory and needs further consideration.

The belief that electropositive sub-atoms carry charges which are equal to or are simple multiples of the negative charge of an electron is a logical deduction from Faraday's laws and the notion of electrical neutrality which is involved in the two fluid theory. Faraday's discovery that the electrolytic separation of the combining weight of any univalent element from any compound was apparently associated with the liberation of the same definite quantity of positive or negative electricity led him to the conclusion that the ions which carry the current in electrolysis part with their charges at the electrodes. This view seems to make necessary the existence of unit positive charges as well as unit negative charges.

We now know, however, that this assumption of a unit positive charge is not necessary, since there is no known case where an ion gives off a positive charge in electrolysis, and we know very certainly that a current in a metallic conductor does not consist of positive and negative charges moving in opposite directions. In the case of the zinc and copper in a Daniell's cell, or in a solution of sulphuric acid, the zinc sub-atom escapes into the solution and sets free in the metal one or more electrons. The positive ions of the solution go to the copper plate and combine with one or more electrons. Neither ion in the solution gives off any electricity to either plate. The fact that a positive sub-atom can only set free or combine with some whole number of electrons does not tell us the magnitude of its positive charge unless we can show that this charge is totally neutralized by the electrons, and this we are unable to do.

The magnitude of the charge of a positive sub-atom has been directly measured in the case of only one element, that of the alpha particle, which has been shown to be the positive sub-atom of helium; but measurements of the magnitude of e/m for a number of positive ions given off by hot bodies have also furnished data from which the charges of the positive sub-atoms of these elements may be calculated. Ruth-

erford and Geiger* and Regener** have measured the positive charge of alpha particles from Ra—C and Polonium and have found this charge to be, within the limits of experimental error, twice as great as the negative charge of an electron. Accordingly when an alpha particle combines with two electrons to form an atom of helium these atoms are as nearly as possible electrically neutral, as is shown by their low cohesion or affinity.

The only circumstances under which we have positive sub-atoms dissociated from their negative ions or electrons seem to be the following:

- (a) The alpha particles in radioactive changes.
- (b) The atomic ions in electrolysis.
- (c) The positive ions spontaneously given off by some hot bodies.
- (d) The ions of gas molecules dissociated by Roentgen rays or by flames or some other agency.
- (e) The canal rays in the vacuum tube, if, indeed, these be positive sub-atoms.

The charge of the alpha particle has already been referred to. The gaseous ions produced by Roentgen rays or other agencies are supposed to become loaded with gas molecules so that their speeds in an electric field are less than they should be for the positive sub-atoms alone, though in the case of ions produced in flames, which will be considered later, it is possible to estimate roughly the charges on certain positive sub-atoms. The attempts to measure the charges on the separate particles in the canal rays have also given inconclusive results. Sir J. J. Thomson† has made many careful measurements on these rays, and he finds the maximum value of $e/m=10^4$, but he finds particles giving every smaller value of this quantity down to zero. This suggests a relation to a recent investigation by Ehrenhaft‡ on the charges carried by very small particles of gold, silver and platinum produced in an electric arc. Ehrenhaft found these little particles to carry charges of all magnitudes from less than 10^{-12} up to 12×10^{-12} . He concludes from these results that there must be charges smaller than the charge of an electron. If

*Rutherford and Geiger, Proc. Roy. Soc. A, lxxxi, 141-162, 1908.

**Regener, Ber. D. Preuss, Akad. D. Wissen., July 22, 1909.

†Thomson, Phil. Mag., xviii, 821, Dec., 1909, xx, 752, Oct., 1910, and xxi, 225, Feb., 1911.

‡Ehrenhaft, Phys. Zeit., xi, 619, July 15, 1910.

it be granted, however, that the positive sub-atomic charges of the metal are not exact multiples of the electronic charge, these small residual charges may be accounted for.

A similar investigation by Przibram* on the charges carried by the particles in the fog produced by phosphorus gives a grouping of charges about values approximating to 4.7×10^{-10} and its multiples, as if the predominant charge were due to one or more electrons, but all kinds of values were obtained from 1.8×10^{-10} to 110×10^{-10} .

In the case of the positive ions produced in electrolysis we know only the magnitude of the negative charges which they may take from the cathode and their average velocity of drift through the liquid under the impulse of a known electric field. We do not know the resistance with which they meet in their movement through the solution, nor through what distances they travel between successive dissociations and recombinations. We know only that if all the ions of a given group have equal positive charges they are acted upon by the same force. If the speeds measured are assumed to be the maximum speeds which the ions can reach in the solution then the slower ions are slower because they are retarded more than the faster ones; but if they move through very short distances as free ions, then their velocity is an accelerated one, and the lighter ions should have the higher speeds. Any hypothesis which undertakes to explain their difference in speed on the basis of a resistance due to the surrounding water would seem to require that the ions having the smallest volumes should have the highest speeds. Thus the attempts which have been made to apply Stokes's equation to their movement would make their velocities vary inversely as their diameters, while, on the contrary, the larger ions of each group have the higher speeds.

On the other hand, if it be assumed that different sub-atoms have different charges, it is very easy to explain the differences in ionic velocities. We are not justified, however, in attempting to calculate the actual magnitudes of these atomic charges without knowing more about the phenomena which are involved in electrolysis. If it be assumed that the ions move very short distances between dissociation and recombination, their motion will be accelerated according to the well known equation, $F=ma$. Since the force acting upon an ion is proportional to its charge, if the ion met with no resistance its charge would be proportional to the product of its mass into its acceleration, and the charges of different ions would be relatively proportional to the products of their ionic masses into their ionic speeds.

*Przibram, *Phys. Zeit.*, xi, 360.

Whatever value may attach to this method of calculating the ionic charges, it leads to some interesting relations not hitherto observed. In the following table are given the hypothetical sub-atomic charges of three well marked groups of similar elements and of hydrogen calculated in this way. The ionic velocities are taken from Lehfeltdt's tables. In the last column are given the ratios of the hypothetical charges of corresponding elements in different groups. It will be seen that for each pair of groups these ratios are constant within the limits of our knowledge of ionic speeds.

Element	Atomic Weight	Ionic Velocity	Ionic Charge	Ratio of Charges
Cs	133	78.8	10480	Cs/I= 1.07
Rb	85.5	78.6	6720	Rb/Br= 1.07
K	39	75.5	2945	K/Cl= 1.09
Na	23	52.6	1210	Na/F= 1.17
Li	7	42.6	298	
H	1	365	365	
I	127	77	9779	I/Ba= 1.04
Br	80	78.1	6248	Br/Sr= 1.06
Cl	35.5	75.1	2666	Cl/Ca= 1.07
F	19	54.4	1034	F/Mg= 1.02
Ba	137.4	68	9343	Cs/Ba= 1.12
Ca	87.6	67	5869	Rb/Sr= 1.14
Sr	40.1	66	2646	K/Ca= 1.11
Mg	24.3	46	1018	Na/Mg= 1.18

The above table indicates not only that the charge of the sub-atom increases when the atomic weight increases, but that it increases according to the same law in each group.

A. A. Noyes and his fellow workers* have shown that as the temperature increases the speeds of several of the electrolytic ions become more and more nearly equal, but he found almost as many cases where the op-

*A. A. Noyes and others, Carnegie Institution Publications, No. 63, 1907.

posite is true. If it could be shown that at the critical temperature of water the speeds of all the electrolytic ions become equal, it would indicate that the ionic charges calculated as above are proportional to the ionic mass. This, it will be shown, is not the case.

ATOMIC CHARGES.

Positive Charges of Ions from Hot Metals.

A more direct method of measuring the charges of positive sub-atoms may be found in experiments carried out by Richardson and Hulbirt* on The Specific Charge of the Ions emitted by Hot Bodies. The authors assume that the ions all carry the same charge, but they give a number of experimental values of e/m which may be used to calculate the relative charges of the positive ions from a number of metals. The experimental difficulties of this investigation were great, and the agreement between the different values obtained for the same metal are not very satisfactory, but, as will be seen from the following considerations, the mean values determined for the different metals are probably not far wrong.

The values of e/m determined by Richardson and Hulbirt for six elements are shown below. Four other elements were used in the investigation, but the values obtained from them were not satisfactory to the authors. Thus two samples of iron gave values of 372 and 409, and the individual values for the same sample differed by more than 100%. Only one measurement was made on osmium. The values obtained for tantalum ranged from 115 to 253 and for tungsten from 47 to 541.

The values given below are those derived directly from the experiment. They were afterward multiplied by a constant to correct for the value of e/m obtained for the electron by the same method; but as the values used in the present paper are only relative this would not affect the result.

*Richardson and Hulbirt, Phil. Mag., xx, 545, 1910.

The second column of the table contains the values of e/m taken from Richardson and Hulbirt's data, and the third column contains the relative values of e found by multiplying e/m by the atomic weight of the element.

Element	e/m	e	Element	e/m	e
Platinum	243	471	Gold	{ 139	273
Palladium	212	225		{ 280	546
Nickel	239	130	Silver	215	232
			Copper	230	146

The elements are arranged in groups according to the periodic law, and it will be seen at once that the values of e for each group are distributed much as are the values of the ionic charges calculated from electrolytic data. It will also be seen that by multiplying the values obtained from electrolytic data by the factor three the two sets of values are made to correspond very closely. This is best shown by arranging both sets of elements according to their position in the periodic table. It was also observed that the charges calculated in this way are very approximately proportional to the square roots of the atomic weights. In the table given below, the number first given under the atomic symbol is the square root of the atomic weight and the second number is the relative atomic charge.

Atomic Charges and Square Roots of Atomic Weights.

H	Li			
1	2.5			
11	9.			
F	Na.	Mg		
4.4	4.8	4.9		
31.	36.	30.		
Cl	K	Ca		
6.	6.2	6.3		
80.	88.	79.	Ni	Cu
			7.6	8.—
Br	Rb	Sr	130.	146.
9.	9.25	9.4		
188.	202.	176.	Pd	Ag
			10.3	10.4
I	Cs	Ba	225.	232.
11.3	11.5	11.7		
293.	314.	280.	?	?
			Pt	Au
			14.—	14.+
			471	546.& 273

This relation is shown more strikingly in Curve I, Plate I, where the atomic charges calculated by the two methods are plotted as abscissas and the square roots of the atomic weights as ordinates. It will be seen that the agreement of the values calculated by the two methods is very close except in the case of gold, where one of Richardson's values lies on each side of the expected value, and of platinum. Strictly speaking, the elements of each group lie on a curve of their own,* but these group curves are parallel and very close together.

*It should be remembered in this connection that the charges of the halogen group were calculated from the velocities of negative ions. They should properly be represented on a branch curve for which the values of the atomic charges are negative. This curve would be perfectly symmetrical with the curve given.

If the quantities calculated by Richardson and Hulbirt for values of e/m are what they were supposed to be, it follows that positive sub-atoms have different characteristic charges which are closely proportional to the square roots of their atomic weights. It also seems to follow that the ions in electrolysis move with accelerated velocities through very small distances between dissociation and recombination.

Charges of Monatomic Gas Molecules.

A method which may be used for estimating, at least roughly, the charges of gas molecules is found in the assumption that cohesion must be at least approximately proportional to the molecular charges. In a paper by W. Sutherland* on the Viscosity of Gases and Molecular Force is given a method of calculating the cohesion between gas molecules from the viscosity of the gases and the laws of the kinetic gas theory. Rankine† has recently measured the viscosity of the gases of the argon group, and has calculated from his data and Sutherland's equation the magnitude of Sutherland's cohesion factor, C , for these gases. His values are as follows: Helium, 70; Neon, 56; Argon, 142; Krypton, 188; Xenon, 252. He calls attention to the evident misfit of helium in this series, since from its low critical temperature it should have much less cohesion than any of the other gases. He finds in the case of the other gases that the ratio of the critical temperature (absolute) to the cohesion factor is about 1.12. By calculating C from this ratio for helium it is found to have a value of about three instead of seventy.

If it be assumed that cohesion is proportional to the atomic charge in these monatomic molecules, then the factor C should be proportional to the square roots of the atomic weights, which it is within the limits of experimental error.‡

Atomic Charges and Solubility.

A similar relation between the same gases is shown in their solubility in water. A. v. Antropoff§ has determined the

*Sutherland, Phil. Mag., xxxvi, 507, 1893.

†Rankine, Physik, Zeitsch, xi, 746, Sept., 1910.

‡Since this paper was in the hands of the printer I find an article by Rankine in the Phil. Mag. of Jan., 1911, p. 45, in which he also relates the viscosities of the gases of the Argon group to the square roots of their atomic weights.

§v. Antropoff, Roy. Soc. Proc., A, lxxxiii, 474, Apr. 14, 1910.

solubility of the above gases in water at different temperatures. For 20 degrees his numbers are as follows: He, .0138; Ne, .0147; Ar, .0379; Kr, .0729; Xe, .1109. The relation between this solubility factor and Sutherland's cohesion factor is apparent at a glance. This is to be expected, since the solubility should be a measure of the cohesion between the gas molecules and water. It will be seen that these solubility factors are also, within the limits of experimental error, proportional to the square roots of the atomic weights, helium, as before, being an exception.

In Curve II, Plate II, the values of Sutherland's cohesion factor as calculated by Rankine and the values of v. Antropoff's solubility factors are plotted as abscissas against the square roots of the atomic weights as ordinates. The solubility factors have been multiplied by the constant 3×10^4 to bring them on the same diagram as the other factors. The points for the cohesion factors are represented by large circles and for the solubility factors by small, black circles. The curve is drawn for v. Antropoff's solubility factors. Helium is seen to depart from the law in the same manner in both cases. If its cohesion factor be used as calculated by Rankine from its critical temperature, it falls directly upon the curve for this factor.

It will be seen that the curve drawn cuts the axis of ordinates at nearly the same point as does Curve I. Accordingly the atomic charges of the elements may be calculated from either curve by using the equation $e = (\sqrt{w} - a) k$, where w is the atomic weight and a is a constant between three and four. The same equation with approximately the same constant may be used to calculate the values of Sutherland's cohesion factor.

The above relations seem to the writer to make the conclusion inevitable that gaseous solubility in water is proportional to the cohesion of the gas molecules for the water molecules, and that this cohesion is proportional to the atomic charges, when the gases are monatomic. In the case of gases having compound molecules the same law would probably hold except that the cohesion would be proportional to the residual molecular charge. Hence gases having high critical temperatures should be more soluble than gases having low critical temperatures.

It is interesting in this connection to note that Traube* and Kleeman† have calculated that the valency of an atom is proportional to the square root of its atomic weight. In the paper referred to, Kleeman

*Traube, *Physick. Zeitsch.*, x, 667, Oct., 1909.

†Kleeman, *Phil. Mag.*, xix, 784, May, 1910.

calculates the value for a number of atoms of a constant C_a which determines the surface tension of the liquid to the molecules of which the atoms belong. This constant depends only upon the nature of the atoms, and is proportional to the square root of the atomic weights. This would seem to make chemical valency as well as cohesion vary directly as the atomic charge.*

Charges of Atomic Ions in Flames.

A condition analogous to the discharge of ions by hot bodies may be found in the dissociation of some metallic salts in a flame. When salts of the alkali metals are dissociated in a Bunsen flame, the outer cone of the flame is colored by the positive ions. T. P. Irving† has shown that when the outer cone is well separated from the inner part of the flame it may sometimes be strongly deflected toward the negative side of an electric field, showing definitely the electropositive character of the ions which give the color to the flame. Irving determined the order of the relative deflection of the ions of different metals in a given electrostatic field. In the case of the ions of the alkali group, which seem most certainly to be dissociated into positive sub-atoms and electrons, he found the order of deflection to be caesium, rubidium, potassium, sodium, lithium. In this experiment, where the ions were most certainly

*Since this paper was ready for the printer I have been able to calculate the compressibilities of a large number of elements from the formula $c = (\sqrt{w-a})k$, the constants a and k varying from group to group, though for several groups a has a value of approximately 3.6. In the electronegative elements the equation takes the form $c = (a-\sqrt{w})k$; that is, the compressibility decreases as the negative charge of the element increases. This would be expected from the fact already mentioned that the more electronegative a metal is in the voltaic series the greater is its cohesion.

I have also been able to calculate the approximate melting points of a considerable number of elements from simple formulae in which the square root of the atomic weight is one factor. Thus the approximate melting point of the alkali metals may be calculated from the formula $(T-a)\sqrt{w} = k$, where T is the melting point (absolute) of the element and a and k are constants for the group. If $a=252.5$ and $k=531.5$ the calculated values of the melting points will vary on the average only .8 of one per cent from the experimental values.

The atomic refraction as calculated by Edwards (*Am. Chem. Jour.*, vols. 16 and 17) and by Eisenlohr (*Zeit. phys. Chem.* LXXV, 585, Dec., 1910), also varies as the square roots of the atomic weights of the elements. No doubt this constant will be found to be an important factor in calculating many other properties of the elements.

†Irving, *Phys. Rev.*, xxix, 248, 1909.

the positive sub-atoms of the metals with all possibility of hydration excluded, the order of deflection is that indicated by the atomic charges of the metals as calculated above, and is the inverse of what it should be if the ions carried equal charges.

The same order also holds in the conductivities of the metallic vapors of this group. The conductivities of flames containing vapors of the metals of this group are given as follows: Caesium, 116; rubidium, 82; potassium, 64; sodium, 8.5; lithium, 2.5.

Atomic Charges and Chemical Valence.

Further arguments against the equality of sub-atomic charges may be found in the phenomena of chemical valence. The writer of this paper, not being a chemist, approaches this part of the argument with a full appreciation of his liability to err from lack of familiarity with the phenomena under consideration. In order to make this liability as small as possible, the discussion will be confined to a few of the phenomena of chemical valence which were quoted by Richard Abegg in his celebrated paper entitled *Die Valenz und das periodische System*.^{*} This selection of phenomena seems all the more suitable for the reason that it was made for the purpose of substantiating an entirely different theory of chemical valence.

As has already been stated several times, the point of view of this paper is that all molecules are made up of electropositive sub-atoms held together by their mutual attractions for the same electron or group of electrons. When a molecule dissociates, the more positive sub-atom holds an excess of the connecting electrons and becomes the negative ion. Thus the hydrochloric acid molecule is presumably made up of two sub-atoms, one of hydrogen and one of chlorine, held together by their mutual attraction for one or more detachable electrons. When they dissociate the chlorine always takes the connecting electron or excess of electrons, if there be more than one, hence it must be the more positive sub-atom; otherwise the attraction between it and the electron would be less than the attraction between the hydrogen sub-atom and the electron.

In the following discussion the propositions regarding valence which are italicised are quoted from Abegg's paper.

All atoms have a definite higher limit to their valency. This will be true if an atom is a positively electrified body attracting to itself

^{*}Abegg, *Zeit. Anorg. Chem.*, xxxix, 330, 1904.

negatively charged electrons, whether its positive charge is some opposite multiple of the electronic charge or not. In any case, after taking on a sufficient number of electrons the system will become negatively electrified and will then repel negative and attract positive charges.

The valence of an element in a compound depends upon the nature of the other component. It is difficult to see how this can be true unless the other components have different electrical charges. If they have equal charges, the same number of their atoms should be held by the charge of the atom under consideration. Where more than one compound may exist between atoms of only two kinds, as in the oxygen and nitrogen series, it would seem that the opposite charges of the two constituents are neither equal nor is one an exact sub-multiple of the other.

All elements vary gradually from each other in their electric affinity. In this statement, gradually apparently does not mean step by step, as they necessarily would vary if they all carried unit elementary charges or multiples of these charges.

In cases where the same element comes out of a compound in several electrovalence steps, the affinities of the higher valencies are generally weaker than the lower. This is shown, according to Abegg, in the fact that the heat of chemical reaction per equivalent is always greater for the lower steps than for the higher. Thus FeCl_3 and FeCl_2 , PbCl_4 and PbCl_2 , etc. The preparation of practically pure compounds of a determined valence step, as for example of FeCl_2 , without the accompaniment of FeCl_3 , shows how enormously different the affinity of the two valence steps must be.

The formation of the higher combination steps, that is to say, the taking up of new valence charges is the more difficult the more charges have already been taken up.

The above propositions from Abegg's paper express exactly the conditions which would prevail from the assumption of the attraction for detachable electrons being the cause of valency. Thus if an electrically charged body have several bodies with electrical charges opposite to its own and equal to each other brought successively into its electrical field, each successive charge will be attracted by a weaker force than its predecessor; while in removing them each successive one will be held by a greater force than the one which preceded it.

The same element may have either a positive or a negative valency. This phenomenon is so well known that no examples need be given. Abegg refers especially to the compound ICl . Here is a compound made up of two atoms both of which may have negative valencies when combined with a metal, yet this compound dissociates in water and the prod-

ucts of its hydrolysis are HCl and IOH . Here the chlorine has taken the negative valence and combines with a positive hydrogen sub-atom, while the iodine replaces a positive sub-atom in the water molecule. Evidently if the chlorine had not had a stronger attraction for the detachable electron than had the iodine it would not have retained it.

Abegg gives hydrogen, boron, silicon, phosphorus, arsenic, antimony, sulphur and iodine as elements which may certainly take either positive or negative valencies according to the element with which they are combined.

The greater the atomic weight of an element in a group the stronger is its positive valence. This is equally true if stated, the greater the atomic weight of an element in a group the more electropositive it is in the voltaic series, and it has already been shown in this paper how the relative charges of the elements in a group may be calculated. Abegg gives many examples of this law. Thus, in the case of nitrogen and phosphorus, nitrogen, the lighter element, can hold only three atoms of chlorine with their attached electrons while phosphorus can hold, though in an unstable condition, five. Oxygen may have in unstable compounds a positive valence of four and sulphur of six. Oxygen is itself negative to sulphur in di-oxide and tri-oxide compounds. Iodine as a positive ion forms with the elements of its own group the compounds IF_3 , ICl_3 , IBr . Bromine, being less positive, can form the compounds BrF_3 , BrCl . Another fact referred to by Abegg which shows the difference in the tenacity with which the elements of this group hold to their valence electrons is shown in the weakening of the affinity of their gas molecules at high temperatures. Thus at high temperatures the iodine molecule dissociates completely, bromine partly, chlorine appreciably and fluorine scarcely at all. This seems to indicate that the charge of the connecting electron or electrons is approximately equivalent to the charges of both fluorine atoms, while in the other elements of the group the positive charge of a single atom becomes more and more nearly equivalent to the negative electronic charge as the atomic weight increases; accordingly the residual charge which constitutes cohesion is greatest for iodine and least for fluorine. Hence iodine is a solid at ordinary temperatures, bromine a liquid, chlorine an easily liquifiable gas and fluorine a relatively permanent gas.

ELECTROMAGNETIC PHENOMENA.

The Electromagnetic Field.

The magnetic effects of an electric current have long been known and the quantitative relations between a current and a magnetic field are well understood, but at the present time no physical theory which will account for these relations has ever been advanced. The fundamental phenomenon seems to be the attraction between two parallel currents in the same direction, and no explanation of this phenomenon seems to be forthcoming. In this respect the present paper does not differ materially from its predecessors. The theory of electric action which has been here outlined does, however, offer certain suggestions which may be worth considering.

A current in a metallic conductor seems to be entirely due to the passage of electrons along the conductor, while in an electrolytic solution it seems to be due to the drifting of both positive and negative ions, though, on the whole, to the positive ions; yet the magnetic effect of a given current seems to be the same in both cases.

That a magnetic field can be produced by the motion of electrical charges has been proved conclusively by Rowland and his students. Since the only phenomenon which we know accompanies an electric charge is an elastic strain in the ether, the magnetic field is apparently due to the motion of these fields of strain through the ether. The preceding discussion has seemed to show that both the electrons in a conductor and the ions in an electrolytic solution are passed along in a succession of periodic flights from one molecule to another. While the electron or ion is associated with an opposite charge in an atom or molecule it can have little, if any, external electric field. While it is moving from one atom to another it will have an external electric field, and since we know of nothing else to produce the magnetic field of a current, we must suppose it to be due to the motion of these short-lived electric fields.

Around a conductor carrying a current these electric fields will spread out with the velocity of light, and their centers of strain will advance with the velocity of an electron in its flight. What this velocity is we have no means of knowing, since we can on any assumption calculate only its average velocity, and we have no means of knowing what part of the time it is at rest. If all the electrons of a given cross section of the conductor advance together, as has been shown to be probable,

then these advancing electric fields form closed loops about the conductor and follow each other at regular intervals. It is easy to see from this view how two parallel currents in opposite directions must repel each other, since these waves going in opposite directions would have to pass through each other, and at such times the amplitude of the strain would be twice as great and the energy of the two sets of waves four times as great as of a single set. It is not so easy to see how two parallel currents in the same direction attract each other. If the waves of the two currents succeed each other at intervals of a half wave length they will, however, attract each other, since there would then be less potential energy of displacement in the ether between the currents than in the ether outside of them, and the reaction to this strain would force the currents toward each other.

Magnetism in Iron.

The question as to how the ether waves considered above would affect a magnet depends upon our theory of magnetism. Here there is substantial agreement upon a few points. The molecular theory of magnetism seems to be unquestioned. Ewing has satisfactorily accounted for the magnetic properties of iron on the assumption that these molecules are persistent and are oriented by their magnetic attractions and repulsions for each other; accordingly that a bar of iron is made an electromagnet by simply having its molecules rotated into a definite orientation.

The only magnetic molecule we know how to construct is one on the pattern of Rowland's rotating disc. Thus a molecule consisting of a number of electrons moving in a more or less circular orbit in a common plane about a positive atom would be such a disc magnet. The Zeeman phenomenon indicates that in some molecules the electrons are moving in broadly elliptical or circular orbits. The spectra of the elements indicate that some molecules have a very large number of electrons capable of vibrating or rotating under the influence of a central force. These spectra also show that iron has the greatest number of these oscillating electrons, nickel next and cobalt next to nickel.

Such a system of rotating electrons would set up a series of rotating strains in the ether following each other around the atom at definite intervals. This condition is strictly analogous to the assumed condition along a wire carrying a current. The waves produced by these rotating electrons travel in opposite directions on opposite sides of the molecule. In a magnet, when these molecular systems are all faced in the same direction and the planes of rotation of their elec-

trons are perpendicular to the magnetic axis, the surface currents produced by their electronic systems are all flowing in the same direction around the magnet. Over the surface of the magnet there is accordingly a series of successive, temporary electric fields moving around the magnet, which are strictly analogous to the temporary electric fields moving along a wire which is carrying a current. Accordingly, if lines of magnetic force are assumed lengthwise along a magnet there must be similar lines of magnetic force encircling a current.

The condition inside a solenoid would then be similar to the condition inside a magnet, except that it would be much less intense. Both regions would be filled with rotating electric fields. The proof of a similar rotation in the two cases is shown in the rotation of the plane of polarization of light. These rotating strains forming a series of vortex waves around the magnetic axis would extend out from both ends of the magnet and solenoid, and would spread through the ether with the velocity of light. When they met and formed closed loops these loops would contract, because the shorter they became the less the potential energy of strain in the ether. These vortex lines from opposite poles of a magnet would accordingly attract each other, while from like poles they would repel each other, like parallel currents in opposite directions.

The position of normal equilibrium of the magnetic molecules in iron would apparently be such that electrons between them would move in the same direction and follow each other, while the condition of magnetic saturation would be unstable, since the electronic fields would move in opposite directions between the molecules and thus increase the strain in the intervening ether.

For the same reason, a magnet in the vicinity of a current would set itself so that the electrons on the side toward the current would be moving in the same direction as those of the current.

The above short discussion of magnetism can be regarded as little more than a suggestion. It is offered in the hope that it may aid in clearing up some of the fundamental difficulties.

APPENDIX.

Note On the Electrical Theory of Benjamin Franklin.

There seems to be a general misunderstanding regarding Franklin's theory of electricity. Smyth, in his *Life and Writings of Benjamin Franklin*, Vol. 1, p. 96, quotes with apparent approval Garnett's *Heroes of Science* as saying of Franklin's views, "They are perfectly consistent with the views held by Cavendish and Clerk Maxwell, and though the phraseology is not that of modern text books, the statements themselves can hardly be improved upon today." Maxwell, in his *Electricity and Magnetism*, Vol. 1, p. 41, describes the one fluid theory of Electricity as follows: "In the theory of One Fluid everything is the same as in the theory of Two Fluids except that, instead of supposing the two substances equal and opposite in all respects, one of them, generally the negative one, has been endowed with the properties and name of Ordinary Matter, while the other retains the name of the Electric Fluid. The particles of the fluid are supposed to repel one another according to the law of the inverse square of the distance, and to attract those of matter according to the same law. Those of matter are supposed to repel each other and attract those of electricity."

Sir Oliver Lodge says on page 202 of his book, entitled *Electrons*: "The positive electron has not, so far as I know, been as yet observed free. Some think it cannot exist in a free state, that it is in fact the rest of the atom of matter from which a negative unit charge has been removed; or, to put it crudely—that 'electricity' repels 'electricity' and 'matter' repels 'matter,' but that Electricity and Matter in combination forms a neutral substance which is the atom of matter as we know it. Such a statement is an extraordinary and striking return to the views expressed by that great genius, Benjamin Franklin."

It is only fair to Sir Oliver Lodge to assume that he has not read Franklin's papers on Electricity, as otherwise he could not have made such a misleading statement in regard to his theory. The other writers who have been quoted as referring to Franklin's electrical theory may not have appreciated the fundamental difference between it and the one fluid theory described by Maxwell, but the author of *Modern Views of Electricity* could scarcely have failed to be impressed with this difference in even a perfunctory reading.

In a paper entitled *Opinions and Conjectures, Concerning the Properties and Effects of the Electrical Matter, etc.*, sent by Franklin to Peter Collinson under date of July 29, 1750, he discusses the nature of the electrical matter which he had previously spoken of as the electrical fire. As this was written at the close of his electrical experiments, three years after he had first proposed the theory of a single electricity, it evidently states his mature views. The first five paragraphs of his discussion are as follows:

"1. The electrical matter consists of particles extremely subtile, since it can permeate common matter, even the densest metals, with such ease and freedom as not to receive any perceptible resistance.

"2. If any one should doubt whether the electrical matter passes through the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him.

"3. Electrical matter differs from common matter in this, that *the parts of the latter mutually attract* (the italics are mine), those of the former mutually repel each other. Hence the appearing divergency in a stream of electrified effluvia.

"4. But though the particles of electrical matter do repel each other, they are strongly attracted by all other matter.

"5. From these three things, the extreme subtilty of the electrical matter, the mutual repulsion of its parts, and the strong attraction between them and other matter, arise this effect, that, when a quantity of electrical matter is applied to a mass of common matter, of any bigness or length, within our observation (which hath not already got its quantity) it is immediately and equally diffused through the whole."

Neither in these paragraphs nor in any other of Franklin's electrical papers have I been able to find any suggestion of the notion that electrical matter and common matter "are equal and opposite in all respects" or that there is such a phenomenon as the "neutralization" of electrical charges, or of electrical matter and common matter. Franklin everywhere speaks of the earth and bodies upon its surface as having a common stock of the electrical fire or electrical matter. In his view, an unelectrified body is one in which the electrical fluid is in equilibrium with that in the earth. A positively electrified body is one in which this fluid has been compressed, and a negatively electrified body is one in which it has been rarefied. This is well shown in a letter to Peter Collinson, dated July 11, 1747. After speaking of two men standing on wax and electrifying themselves, one from a glass tube and the other from the rubber, while a third man stands on the floor near them, he

says, "These appearances we attempt to account for thus: we suppose, as aforesaid, that electrical fire is a common element, of which every one of the three persons above mentioned has his equal share, before any operation is begun with the tube. A, who stands on wax and rubs the tube, collects the electrical fire from himself into the glass; and his communication with the common stock being cut off by the wax, his body is not again immediately supplied. B (who stands on wax likewise), passing his knuckle along near the tube, receives the fire which was collected by the glass from A; and his communication with the common stock being likewise cut off, he retains the additional quantity received. To C, standing on the floor, both appear to be electrified: for he having only the middle quantity of electrical fire, receives a spark upon approaching B, who has an over quantity; but gives one to A, who has an under quantity. If A and B approach to touch each other, the spark is stronger, because the difference between them is greater; after such touch there is no spark between either of them and C, because the electrical fire in all is reduced to the original equality."

These quotations seem to make it certain that Franklin regarded the earth and all bodies on its surface as being at all times charged with electricity, and that an insulated body was regarded as electrified only when its electrical charge was not in equilibrium with the electrical charge of the earth. In this respect his one fluid theory is fundamentally different from the one fluid theory as defined by Maxwell.

PLATE I.

Square roots of atomic weights.

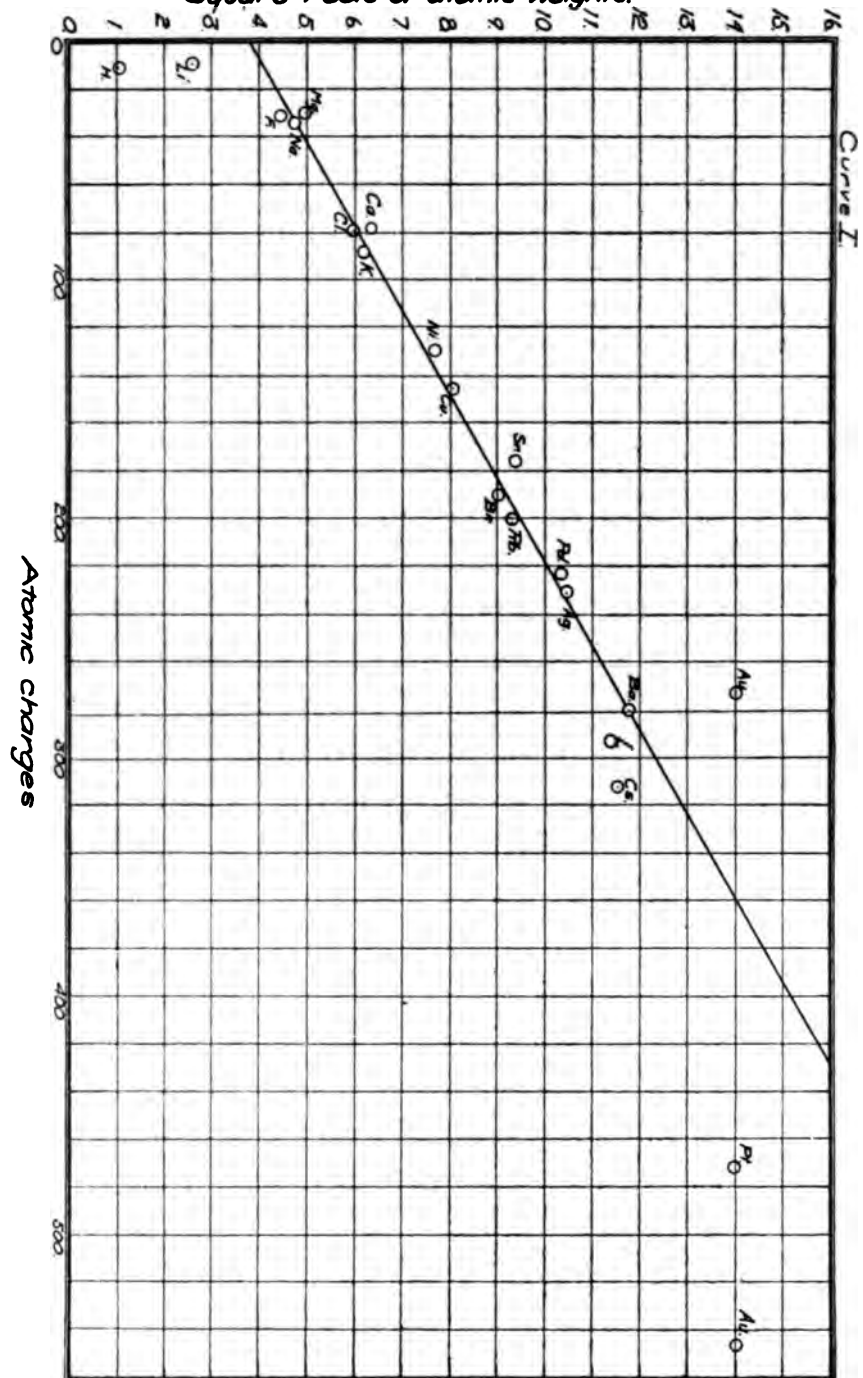
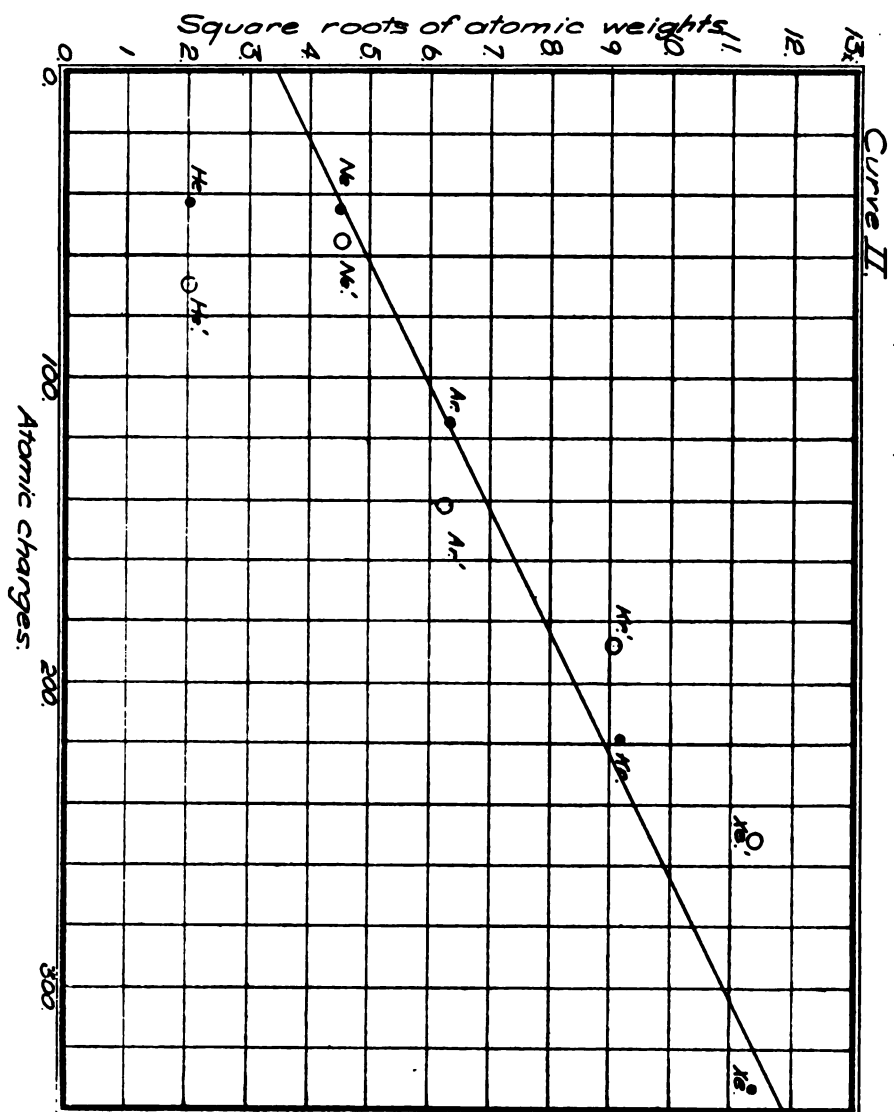


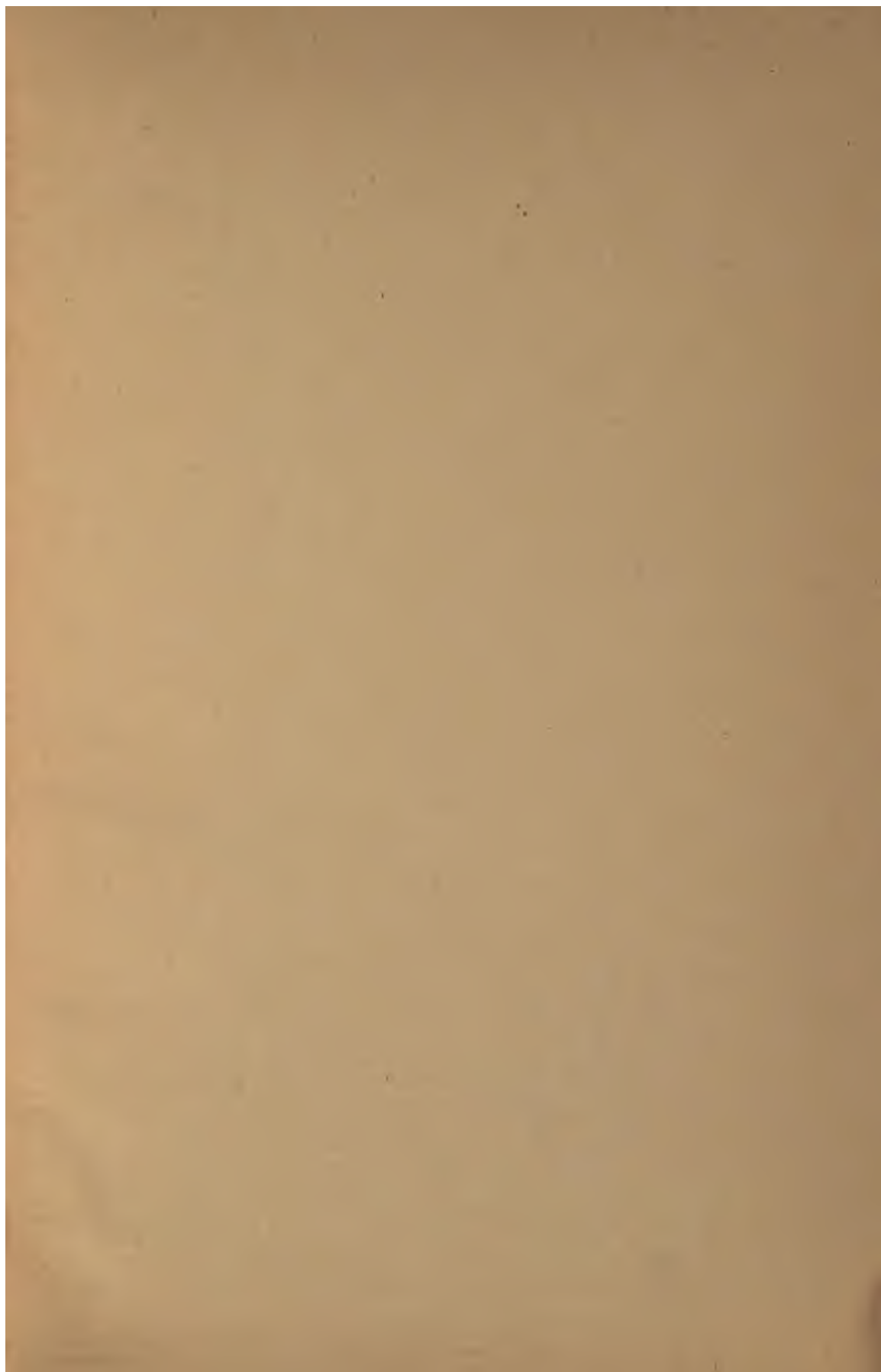
PLATE II.



1. The first part of the document is a list of names and addresses of the members of the committee.

2.

3.







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